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Section A

THEORETICAL

1. Plastic-elastic models. B. PERSOZ, *Rheologica Acta*, 1958, **1**, 90–96. 68 Bd. St. Michel, Paris. General combinations of one-dimensional models of Maxwell and Kelvin type are considered, in which dashpots (viscous elements) are replaced by idealized plastic elements whose force–deformation properties are similar to the force–displacement properties of the contact between a pair of solids having a finite constant static coefficient of friction and zero kinetic coefficient of friction. [French] A.S.L.

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2. "Boltzmann" viscoelastic bodies. J. MANDEL, *Rheologica Acta*, 1958, **1**, 127–130. École Polytechnique, Paris. The use of Laplace (or, more conveniently, Carson) transforms to reduce problems concerning isotropic, linear viscoelastic materials to problems concerning isotropic, linear elastic solids is extended to include inertial terms. The flexure of a loaded beam is considered as an example. [French] A.S.L.

3. Deformation of networks by detachment and formation of cross-links. FUMIO OOSAWA, *J. Polym. Sci.*, 1958, **32**, 229–246. Dept. of Physics, Faculty of Science, Nagoya University, Nagoya, Japan. The behaviour is considered of an elastic network in which cross-link detachment occurs under various states of deformation. It is shown theoretically that the effect of such detachment (upon the strain of the system at constant stress) depends upon both the state of deformation when the detachment takes place and that under which the cross-link was originally formed. The case of solvent-swollen networks is also considered. The results are of use in analyzing the behaviour of living muscle. E.B.A.

4. Single lines in retardation and relaxation spectra. B. GROSS, *Rheologica Acta*, 1958, **1**, 131–133. National Institute of Technology, Rio de Janeiro, Brazil. It is shown that if the retardation (or relaxation) spectrum is zero outside and different from zero inside *and at the ends* of a finite interval, the relaxation (or retardation) spectrum always contains a single line outside the interval. When there is no discontinuity at the ends of the interval, conditions for the existence of a line are given. A.S.L.

5. Stresses and strains in an infinite elastic sheet under a tension applied at two rigid pairs of square jaws. D. G. PADFIELD and N. B. DICKINSON, *Brit. J. Appl. Phys.*, 1958, **9**, 448. Wool Industries Research Association, Leeds. First-order elastic theory of plane stresses is applied numerically to obtain estimates of the stresses in an infinite elastic sheet stretched in its own plane. For comparison, a similar method was used to determine the stress in a strip tensioned by forces applied at rigid jaws extending across the whole width of the strip. G.M.J.

6. The relationship between the stress tensor and deformation rate tensor in the general case of large and small deformations. G. I. GUREVICH, *Dokl. Akad. Nauk SSSR*, 1958, **120**, 987. [Russian]

7. On the theory of linear dissipative systems. J. MEIXNER and H. KÖNIG, *Rheologica Acta*, 1958, **1**, 190–193. Rheinisch-Westfälische Technische Hochschule, Aachen. The recent discovery of mechanical *resonance* absorption in metals and crystalline polymers suggests that the customary description of linear viscoelastic systems in terms of real, positive relaxation periods is too restrictive. The results of a rigorous, one-dimensional, more general, mathematical treatment based on assumptions of linearity, causality, invariance to change of time scale, etc., are stated. It is shown, for example, that the usual assumption that a liquid under constant stress will ultimately reach a state of steady flow is not necessarily valid. [German] A.S.L.

8. On the problem of uniqueness in the theory of a rigid-plastic solid—IV. R. HILL, *J. Mech. Phys. Solids*, 1957, **5**, 302–307. In part III of this series a sufficient condition, in terms of the rate of work hardening, was obtained for the uniqueness of the deformation mode in a properly formulated boundary-value problem. The unique mode is now characterized by an extremum property in the set of virtual modes. This is a generalization of one obtained in part I, in that it takes due account of changes in geometry. The three previous parts are published in *J. Mech. Phys. Solids*, 1956, **4**, 247; 1957, **5**. 153. Author

9. Flow anisotropy in the theory of liquids. J. V. CHAMPION, *Proc. Phys. Soc.*, 1958, **72**, 711–716. Sir John Cass College, London. From the theory of EISENSCHITZ (1949) on the steady non-uniform state of a liquid, a magnitude has been calculated for the anisotropy of flow in a liquid due to a distortion of the radial distribution function by a shearing force. The optical anisotropy has been obtained by using the BRAGG (1924) method of calculating double refraction from the variation of the polarization due to the distorted distribution function. The value $n=7{\cdot}1\times10^{-8}$ (calculated for chloroform, for which the distribution function is known and of which the polarizability dies not differ greatly from that of carbon tetrachloride) shows that the effect may be detected experimentally in a liquid normally isotropic. The calculation also shows that the main contribution to the anisotropy arises from small values of the range, r, and the magnitude of the anisotropy is independent of the precise way in which the distortion decreases at large distances. This implies that the "strong" condition of EISENSCHITZ cannot be supported by an appeal to the isotropy of flow. Author

10. On the theory of Maxwellian liquids. H. JUNG, *Rheologica Acta*, 1958, **1**, 280–285. Stuttgart N, Robert-Mayer Str. 66, Germany. Time derivatives of a stress tensor associated with a deforming continuum are considered. Particular forms of rheological equations of state are advanced describing a compressible solid and a compressible liquid, and are applied to shear deformations. [German] A.S.L.

11. Poro-plastic deformation. B. R. SETH, *Rheologica Acta*, 1958, **1**, 316–318. Indian Institute of Technology, Kharagpur, India. A yield criterion is given in terms of finite-strain components for a transversely isotropic plastic solid and the resulting equations are applied to the problem of bending a plane plate into the form of a cylinder. As in the

corresponding problem for an isotropic material, the bending moment is found to be proportional to the square of the thickness. A.S.L.

12. Plastic flow and fracture in solids. T. Y. THOMAS, *J. Math. Mech.*, 1958, **7**, 291–322. Graduate Institute of Mathematics and Mechanics, Bloomington, Indiana. Deals with the following points for an ideal solid which obeys the linear theory of elasticity up to the yield point and is governed by the Prandtl–Reuss theory in the plastic region : fracture along Lüder's bands, weak discontinuities, transition from elastic to plastic state without fracture, and fracture in the direction of tension. R.R.

13. Some geophysical applications of the elasticity theory of dislocations. J. A. STEKETOE, *Canad. J. Phys.*, 1958, **36**, 1168–1198. Dept. of Applied Mathematics, University of Toronto, Toronto, Ontario. Some aspects of the elasticity theory of dislocations (E.T.D.) which may be of geophysical significance are discussed. The central position of A- and B-nuclei of strain in this theory is emphasised. Applications to cracks and seismological models are indicated. Some limitations of the E.T.D. for applications to geophysics appear in the discussion of strain energy. Finally the displacement field at the surface of a semi-infinite elastic medium which contains a particular B-nucleus at depth c is discussed. The paper indicates the analogy of E.T.D. with potential theory. M.F.C.

14. The random-walk model with autocorrelation of flow through porous media. A. E. SCHEIDEGGER, *Canad. J. Phys.*, 1958, **36**, 649–658. Research Laboratory, Imperial Oil, Ltd., Calgary, Alberta. In pursuit of the idea of applying statistical mechanics to the theory of flow through porous media, this paper reports an investigation of the implications of a random-walk model as opposed to random residence-time models. Although the random-walk model is physically not as satisfactory as other statistical models, it has the advantage of enabling one to introduce and to investigate easily the effect of autocorrelation between subsequent time steps. It is shown that, if autocorrelation exists, the mixing process in porous media is governed by a telegraph equation rather than by a diffusivity equation. Expressions for the constants occurring in the telegraph equations are deduced in terms of other dynamical variables. Author

15. Forces on cylinders and plates in an oscillating fluid. G. H. KEULEGAN and L. H. CARPENTER, *J. Res. Nat. Bur. Stand.*, 1958, **60**, 423–440. National Bur. Standards, Washington, D.C. The inertia and drag coefficients of cylinders and plates in simple sinusoidal currents are investigated. The midsection of a rectangular basin with standing waves surging in it is selected as the locale of currents. A full theoretical treatment is given, together with photographic examination of the flow patterns. The significance of the parameter U_mT/D is discussed, where U_m is the maximum intensity of the sinusoidal current, T is the period of the wave and D is the diameter of the cylinder or the width of the plate. M.F.C.

16. On non-existence of rectilinear motion in plastic solids and non-Newtonian fluids. D. E. STONE, *Quart. Appl. Math.*, 1957, **15**, 257–262.

17. On the application of infinite systems of ordinary differential equations to perturbations of plane Poiseuille flow. C. L. DOLPH and D. C. LEWIS, *Quart. Appl. Math.*, 1958, **16**, 97–110. University of Michigan, Ann Arbor, Michigan. The method developed, which is based on earlier work by E. HOPF, gives additional evidence of the instability of plane Poiseuille flow. The same techniques appear capable of furnishing a rigorous treatment of the transition to turbulence, since in principle their scope is not limited to linear problems. R.R.

18. Stoke's and Einstein's Law for non-uniform viscosity. S. BROERSMA, *J. Chem. Phys.*, 1958, **28**, 1158. Dept. of Physics, Northwestern University, Evanston, Illinois. The paper treats the case where the viscosity of the fluid in the neighbourhood of a particle is non-uniform, and varies such that

$$\eta_{cm}/\eta_{(r)} = 1 - \epsilon_m (am/r)^m$$

Equations are obtained for the force resisting relative motion of a spherical particle and the medium, the viscosity of dilute suspensions, diffusion coefficients etc. The results are applied to the theory of gel formation and to experimental studies of proton relaxation times in diamagnetic solutions and self-diffusion of protein and solvent molecules. E.B.A.

19. Role of volume effects in the theory of deformations of reticular polymers. T. N. KHAZANOVICH, *Zh. tekh. fiz.*, 1958, **28**, 1437. [Russian]

20. Solute migration in macromolecular solutions in shear flow. F. SCHULTZ-GRUNOW, *Rheologica Acta*, 1958, **1**, 289–296. Inst. für Mechanik der Technischen Hochschule, Aachen, W. Germany. A calculation shows that, in the shear flow of a suspension of independent particles in a liquid of zero viscosity, hydrodynamic forces arising from the solvent inertia give rise to forces near a rigid wall such as to repel solute particles from the wall. Experiments are performed in which a 0·02 per cent solution of polystyrene in toluene flows (at an unstated rate) through a tube of rectangular cross-section (8 cm × 1 cm) having glass walls. A parallel beam of light passing through the liquid parallel to the 8 cm dimension is refracted near the walls when the flow takes place giving the appearance of layers, 2·5 mm thick, in which concentration gradients are set up. [German] A.S.L.

21. Streaming dichroism in polymer solutions : The calculation of results. G. R. BIRD, *J. Chem. Phys.*, 1958, **28**, 1155–1158. Polaroid Corp. Research Div., Cambridge, Mass. Streaming dichroism of the infra-red absorption bands of polymer solutions has been observed by flowing the solutions through a modified infra-red cell. The calculation of orientation and dichroism as a function of streaming gradient resembles the calculation for streaming birefringence but is not identical. This calculation is performed for ellipsoidal particles, and the results tabulated for the special case of rods with high axial ratio. Author

22. Structural changes induced by flow. M. JOLY, *Rheologica Acta* 1958, **1**, 180–185. Institut Pasteur, Paris. Semi-quantitative theoretica[1] treatments are given (i) for changes of phase stimulated by shear flow in pure liquids composed of strongly-interacting molecules, and (ii) for changes in the state of aggregation stimulated by shear flow in suspensions of spheres and in suspensions of rodlets. [French] A.S.L.

23. Tensile strength of plastics: effects of flaws and chain relaxation. F. BUECHE, *J. Appl. Phys.*, 1958, **29**, 1231–1234. A theory for the tensile strength of amorphous plastics is presented. It extends a previous theory so as to include the effects of imperfections and chain relaxations. The result obtained shows that the time taken for a plastic to break, t_c, under constant stress, F, is given by

$$F = B \ln (t_c) + C,$$

where B and C are molecular constants. The experimental values found for these constants are shown to be consistent with their molecular interpretation. This extended theory shows that the effect of chain relaxations is the major time dependent factor as far as strength is concerned. Author

24. Cohesive energy densities of polymers—II. Cohesive energy densities from viscosity measurements. G. M. BRISTOW and W. F. WATSON, *Trans. Faraday Soc.*, 1958, **54**, 1742, 1747. The British Rubber Producers' Research Assoc., Welwyn Garden City, Herts. Values are deduced for the interaction parameter χ for polymethyl-methacrylate, polystyrene, and polyvinyl chloride systems by an application of the Fox–Flory theory to the viscosities of a polymer fraction in a suitable range of solvents. Analysis of the values as in part I leads to the assignment of cohesive energy densities for the polymers. For natural and butyl rubbers it is shown that the analysis of viscosity and swelling measurements lead to identical values of cohesive energy density. Author

Section B

INSTRUMENTS AND TECHNIQUES

25. Measuring viscosity at very high temperature. ANON, *Fluid Handl.*, 1958, 219 ; *Lab. Practice*, 1958, **7**, 479–480. The U.S. National Bureau of Standards is developing an oscillating cup viscometer to measure the viscosity of liquid inorganic oxides at temperatures up to 2000°C. This method is used because of the low viscosities of the liquids. The principle of the method is briefly discussed and the problems associated with these high temperatures are dealt with. E.B.

26. Viscosity determination by the oscillating vessel method—I. Theoretical considerations. R. ROSCOE, *Proc. Phys. Soc.*, 1958, **72**, 576–584. King's College, Newcastle upon Tyne. When a liquid is placed in a vessel held by a torsional suspension and the whole is set in rotation about a vertical axis, the viscosity of the liquid may be deduced from

observations of the time period and decrement of the oscillations. This method of measuring viscosity has many practical advantages, but there are mathematical difficulties in making the calculations. The cases of spherical and cylindrical vessels are considered in detail and formulae are obtained for the calculation of the viscosity which are very accurate and easier to use than those previously proposed. The case of an axially symmetrical vessel which departs slightly from the spherical form is also considered, and formulae (valid only when the frequency of oscillation is high) are obtained for an axially symmetrical vessel of any shape. Corrections for the effect of external air resistance are also discussed. Author

27. Viscosity determination by the oscillating vessel method—II. The viscosity of water at 20°C. R. ROSCOE and W. BAINBRIDGE, *Proc. Phys. Soc.*, 1958, **72**, 585–595. King's College, Newcastle upon Tyne. The practical possibilities of the oscillating vessel method for accurate absolute measurements have been investigated. An improvement in Andrade and Chiong's apparatus was effected by using a capillary tube for the stem of the spherical bulb so that the liquid acted as its own thermometer. Abnormally large logarithmic decrements were found to occur with large amplitudes of rotation, and attention has been given to the best statistical method of calculating the decrement while avoiding this effect. A value of $1{\cdot}0025 \pm 0{\cdot}0005$ cP was obtained for the viscosity of water at 20°C, but an analysis of the sources of error indicates that the accuracy could be increased by further improvements well beyond that of the best capillary tube determination ($1{\cdot}0019 \pm 0{\cdot}0003$ cP). These improvements would include the replacement of the spherical bulb by a cylindrical vessel.
Author

28. Viscometer for the rapid determination of viscosities at a single concentration. N. SCHNEIDER, *J. Polym. Sci.*, 1958, **32**, 253–255. U.S. Army, Quartermaster R & E Center, Pioneering Research Division, Natick, Massachusetts, U.S.A. The viscometer described incorporates the "suspended level" principle but eliminates the necessity of rinsing and drying between samples. It should therefore be of considerable advantage in quickly analysing the results of chromatographic fractionation of high polymers. E.B.A.

29. A modified method for measuring surface viscosity. R. BULAS and C. A. KUMINS, *J. Colloid Sci.*, 1958, **13**, 429–440. The Research Laboratories, Interchemical Corporation, New York, N.Y. The oscillating disc method for measuring the surface viscosity has been used without recourse to a reference liquid. It has been found that for a pure liquid the logarithmic decrement obtained with the disc positioned in the liquid is twice as large as that obtained with the disc oscillating at the surface of the liquid, providing the distance from the disc to the surface of the liquid and to the bottom of the container is greater than a critical distance h_c. A method of determining the critical distance is described and an equation describing the relationship between h_c and the bulk viscosity of the solution is presented. The results obtained in the determination of surface viscosity using this method are shown and are compared with those obtained with the conventional technique using an external standard.
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30. A rotation viscometer measuring directly the ratio of the shearing stress to the rate of shear. H. EISENBERG, *J. Sci. Instrum.*, 1957, **28**, 927–932.

31. A rotational viscometer for thinning paint samples. C. J. H. MONK, *J. Oil Col. Chem. Ass.*, 1958, **41**, 599–606. Imperial Chemical Industries Ltd., Paints Division, Wexham Road, Slough. The torque exerted on a stirrer used to agitate a paint mixture in a standard vessel is used, either as a measure of viscosity ($\pm 0{\cdot}05$ P) or to control the thinning operation. The instrument is virtually self cleaning. W.H.B.

32. Influence of the heat generated on the determination of viscosity in a Couette viscometer. H. ZEIBIG, *Rheologica Acta*, 1958, **1**, 296–299. Inst. für Mechanik der Technischen Hochschule, Aachen, W. Germany. Previous calculations of the viscous heating effects in a concentric cylinder viscometer whose inner cylinder is thermally insulated and whose outer cylinder is kept at a constant temperature are extended by allowing for the change of viscosity of the test liquid with temperature. Calculated relations between angular velocity of the outer cylinder and torque agree well with data obtained with a sample of tar, and a procedure is given for calculating the isothermal relation between shear stress and rate of shear. [German] A.S.L.

33. The Micro-Elastometer : a micro-device for measuring the modulus of " stiffness " of small samples of thermoplastic materials. J. W. A. LABOUT, *Rheologica Acta*, 1958, **1**, 186–189. Koninklijke/Shell-Laboratorium, Amsterdam. About 10 mm³ of asphaltic bitumen samples are subjected to oscillatory shear at frequencies between 4 and 500 c/s in the gap of a small cone-and-cone viscometer whose cone semi-vertical angles are 23° and 37°. The moment of inertia of the oscillating cone is varied, and the phase differences between force and displacement are measured. Values of the complex modulus are deduced, the required constant of the apparatus being evaluated by a calculation and checked by independent measurements on vibrating rods. A.S.L.

34. The elastometer, a simple device for measurement of elastic moduli of plastics at elevated temperatures. R. A. SPURR, M. J. HELDMAN and H. MYERS, *Bull. Amer. Soc. Test. Mat.*, 1958, No. 231, 65–67. Hughes Aircraft Co., Culver City, California. The elastic modulus of rigid plastics can be determined at elevated temperatures by measuring the frequency of the first resonance of a clamped reed. The apparatus and a few experimental results are described. E.B.A.

35. Comparison of methods for determining intrinsic viscosities from non-Newtonian viscosities. K. H. CRAM and J. C. WHITWELL, *Text. Res. J.*, 1958, **28**, 849. Textile Research Institute and the Department of Chem. Eng., Princeton University, Princeton, New Jersey, U.S.A. Absolute flow curves for solutions of two samples of cotton cellulose at concentrations of $0{\cdot}1$, $0{\cdot}2$ and $0{\cdot}3$ g/100 ml in 0·5M cupriethylenediamine were determined over a shear stress range of $0{\cdot}01$–1000 dyn cm^{-2}. Both rotational and capillary viscometers were employed. A.K.

36. Contributions to the knowledge of stirring—II. Indication of flow paths by means of a suspended body. A statistically-based method of investigating the process of stirring in the liquid phase. H. STEIDL, *Coll. Trav. Chim. Tchécosl.*, 1958, **23**, 1664–1679. Department of Chemical Engineering, Technical High School for Chemistry, Prague. It is shown that quantitative information about the effect of changing stirring conditions on the state of flow in a stirring apparatus can be obtained from observations of the movement of a suspended test-body in the form of three equal, concentric, mutually perpendicular, circular discs whose lines of intersection are soldered together and given distinguishing marks. [German] A.S.L.

37. Rheological properties of two-phase multi-component systems involving liquid-phase separation, with special reference to soap. H. HEIN, *Rheologica Acta*, 1958, **1**, 286–289. Inst. für Mechanik, Technische Hochschule, Aachen, W. Germany. The pressure gradients in the flow of soap through tubes of diameter 2 cm and 3 cm are determined from measurements of the elastic extension of the tube walls for temperatures in the range 34°C to 42°C. The data are interpreted in terms of plug flow and thickness of a low-viscosity layer at the wall. [German] A.S.L.

38. Determination of rheological polydispersion by means of PD-characteristic curves. J. SCHURZ and H. STREITZIG, *Monatsh.*, 1958, **89**, 229–233. [German]

39. Rheology of bitumens. F. SCHLOSSER and F. HEMPEL, *Erdöl u. Kohle*, 1957, **10**, 232–238 ; *J. Appl. Chem.*, 1957, **7**, 395. Relation between dynamic viscosity and standard test methods for bitumens and similar thermoplastics.

40. Normal thrust in dynamic torsion for rubber-like materials. A. F. H. WARD and G. M. JENKINS, *Rheologica Acta*, 1958, **1**, 110–114. Faculty of Technology, University of Manchester. The total normal force and torque applied to the ends of a cylindrical sample of rubber subjected to finite torsion varying sinusoidally with time are measured. Data are given for different frequencies (0·01 to 10 c/s) and temperatures (20°C to 75°C) on 5 samples of natural rubber having different degrees of cross-linking. In one case, the effect of varying the length and diameter of the sample and the amount of torsion are investigated. The phase angle between torque and strain is measured ; no phase angle between torque and normal force could be detected. The normal thrust varies at twice the frequency of the torque ; the " troughs " of the thrust trace lie above the line of zero thrust. The results are compared with the predictions of the Mooney form of stress–strain relation for a perfectly elastic solid, and, at each frequency, values of the two " constants " C_1, C_2 are derived. C_1 increases with degree of cross-linking as usual, and is practically independent of frequency ; C_2 shows a marked decrease with increasing degree of cross-linking, and is appreciably dependent on frequency. A formal generalisation, involving time-integrals of strain, of Mooney's relations is advanced. A.S.L.

41. Determination of dynamic mechanical characteristics of materials by a method of bend vibrations in a thin plate attached at one end. A. V. SIDOROVICH and E. V. KUVSHINSKII, *Zh. tekh. fiz.*, 1958, **28**, 1759. [Russian]

42. The calculation of the mean value and standard deviation of bursting elongation. H. VIETH, *Faserforschung*, 1958, **9**, 388–391. Deutsche Akademie der Wissenschaften zu Berlin, Institut für Faserstoff-Forschung in Teltow-Seehof, Germany. In a series of replications of bursting strength tests with a given apparatus, sufficiently accurate results are obtained if the mean bursting elongation is calculated from the *mean* of the heights of the inflated arch at burst. [German] A.S.L.

43. Dynamic properties of tyre cords subjected to an oscillating tensile stress. G. KEMMNITZ, W. MESKAT and H. MEUMANN, *Rheologica Acta*, 1958, **1**, 268–274. Farbenfabriken Bayer A.G., Leverkusen-Bayerwerk, W. Germany. A sample of tyre cord is subjected to an oscillating extension of specified amplitude and frequency. The amplitude and phase of the corresponding tensile stress is measured electronically. Different methods of calculating the mechanical damping are compared, data being given for several types of viscose tyre cords. For one type, data for damping and dynamic modulus at 50 c/s are given for different conditions of twist. [German] A.S.L.

44. The measurement of the strain-dependent damping of metals vibrating torsionally. G. SUMNER and K. M. ENTWHISTLE, *Brit. J. Appl. Phys.*, 1958, **9**, 434. Dept. of Metallurgy, Manchester University. Apparatus is described for the above measurement at room temperature with shear strains of up to 2×10^{-3} for mild steel. Vibrations are maintained by a moving-coil exciter controlled by a Rochelle Salt detector coupled to the end of the specimen. The phase of the exciter current is adjusted to coincide with that of the angular velocity of the specimen so that absolute values of energy loss can be obtained. Values for an Al alloy agree with the decrement measured by free-decay test, not so for ferromagnetic materials. G.M.J.

45. Explosive press for use in impulsive loading studies. EDWARD W. LA ROCCA and JOHN PEARSON, *Rev. Sci. Instrum.*, 1958, **29**, 848–851. Michelson Laboratory, U.S. Naval Ordnance Test Station, China Lake, California. Small explosively activated presses have been used as research tools in the study of the behaviour of powdered materials under impulsive loads. Estimates of the pressures which can be obtained are on the order of several million pounds per square inch. Operation of three presses and their application to the study of several materials are described. H.J.R.

46. Elastic constant–internal friction spectrometer. D. O. THOMPSON and F. M. GLASS, *Rev. Sci. Instrum.*, 1958, **29**, 1034–1040. Oak Ridge National Laboratory, Oak Ridge, Tennessee. An elastic constant–internal friction spectrometer has been developed which has proved to be very useful in measurements which must last over extended periods of time as well as in measurements which require a high degree of reso-

lution. The essential feature of the spectrometer is the fact that it holds the sample in oscillation at its resonant frequency and at a preset strain amplitude and measures the internal friction of the sample through a measurement of the driving power necessary to maintain the preset amplitude. H.J.R.

47. Low temperature cracking test for plasticised P.V.C. D. WORMALD, *Brit. Plast.*, 1958, **31**, 392. Dr. Rosin Industrial Research Co. Ltd. A strip of plastic is repeatedly folded and unfolded by means of a solenoid actuated clamps in a cold cabinet. A probe tests the sample for breaks at the end of each cycle. Results are given for the flex life of a number of plasticised P.V.C. compositions. E.B.A.

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48. The low-temperature brittleness testing of polyethylene. P. N. BESTELINK and S. TURNER, *A.S.T.M. Bull.*, 1958, No. 231, 68–73. I.C.I. Plastics Division, Welwyn Garden City. Describes an apparatus for determining the " brittleness temperature " of polyethylene. Twenty specimens are tested at a time by bending, and the apparatus can accommodate 160 specimens. Temperature control is by means of dry air passed through a heat exchanger. An automatic notching machine for preparing specimens is also described. The standard deviation of brittleness temperature measured in this way on notched specimens is only 1 or 2°C. E.B.A.

49. The determination of the glass transition temperature of polyethylene by X-ray diffraction. S. M. OHLBERG and SUE S. FENSTERMAKER, *J. Polym. Sci.*, 1958, **32**, 514–516. Koppers Co. Inc., Verona Research Center, Verona, Pennsylvania, U.S.A. The diffraction angle at maximum intensity of the main amorphous halo in the X-ray diffraction pattern is used to estimate the mean interchain separation in the amorphous regions of cold-drawn polyethylene film. Measurements were made over a temperature range of 24 to −100°C and the plot of amorphous chain separation against temperature was found to consist of two straight lines intersecting at −28°C. This temperature is taken as the glass transition temperature which is better defined by this method than by conventional ones. The linear expansion coefficients in the two portions of the plot are discussed. E.B.A.

50. Some modifications of the design and use of the " Research " water absorption meter in relation to consistency measurements of single doughs. H. G. MULLER and L. F. BARRON, *J. Sci. Fd. Agric.*, 1958, 638–644. The Laboratory, Symbol Biscuits Ltd., Devonshire Road, Blackpool. The standard " Research " water absorption meter has been modified by surrounding the cup with a water jacket in order to eliminate the use of a constant-temperature room. Standardisation of dough handling has been achieved by the use of two mechanical moulding devices for filling the cup. The standard deviation of sets of duplicate determinations are given as obtained by a trained and untrained operator using the standard technique and by the use of a mechanical moulding method. By obtaining a four-point curve from a single test dough, the effect of various ingre-

dients on the consistency of dough is described, and it has been shown that it is possible to obtain dough relaxation curves similar to those obtained by using load extension tests. H.G.M.

51. Analytical study of plastics extrusion. Y. MORI and T. K. MATSUMOTO, *Rheologica Acta*, 1958, **1**, 240–242. University of Tokyo. It is found that, contrary to common belief, granular polymers do not move as a solid plug during passage through the first part of a screw extruder. Pressure is measured at points on the wall along the rest of the extruder up to the die entry and is found to agree well with values calculated on the basis of a dimensional analysis combined with measurements of wall temperature and knowledge of temperature–viscosity behaviour. A.S.L.

52. Development and testing of synthetic fibres having shaped cross-sections with and without hollow spaces. H. BÖHRINGER and F. BOLLAND, *Faserforschung*, 1958, **9**, 405–416. Institut für Textiltechnologie der Chemiefasern, Rudolstadt-Schwarza, Germany. Using specially-shaped spinneret holes, fibres are spun having cross-sections of various shapes e.g. star-shaped, re-entrant, tubular. The properties of yarns and fabrics made from these fibres are compared. [German] A.S.L.

Section C

METALS AND OTHER SOLIDS

53. Erosion damage to solids caused by high-speed collision with rain. OLIVE G. ENGEL, *J. Res. Nat. Bur. Stand.*, 1958, **60**, 47–52. National Bureau of Standards, Washington, D.C. The stresses that are produced when a liquid drop collides with the planar surface of a solid are discussed. These are the result of the impact pressure and the subsequent radial flow of the drop. It is concluded that a rain-erosion resistant material may be either soft and rubbery or hard and rigid. M.F.C.

54. The formation of new surfaces in the deformation and rupture of a solid body in a surface-active medium. E. D. SHCHUKIN and P. A. REBINDER, *Kolloidnyi Zh.*, 1958, **20**, 645. Dept. of Dispersed Systems, Acad. Sci. U.S.S.R., Inst. of Physical Chemistry, Moscow. Surface-active materials may cause brittleness in crystals or an increase in plasticity. Optimal conditions of temperature and rate of deformation have been determined. Normal and shear stresses at brittle rupture and conditions for transition from brittle to plastic failure have been calculated. [Russian] English abstract. G.W.S.B.

55. On the rheology of metals in surface-active media. V. S. OSTROVSKIĬ and V. I. LIKHTMAN, *Kolloidnyĭ Zh.*, 1958, **20**, 640. Dept. of Dispersed Systems, Acad. Sci. U.S.S.R., Institute of Physical Chemistry, Moscow. Creep tests of tin and lead have been made under uniform shear conditions over a large range of stresses and at different temperatures. It has been

shown that the maximum plastic viscosity at small stresses above the creep limit is independent of the stress. At high stresses an abrupt fall takes place in the plastic viscosity which leads to the independence of the critical shearing stress from the deformation rate. At elevated test temperatures a regular decrease in plastic viscosity and in the yield value is observed, attaining zero value at a given temperature. A surface-active medium facilitates the plastic flow of metal. The effect is manifested in a lowering of the ultimate viscosity and yield value. The maximum adsorption effect corresponds to the range of shearing stresses lying at the upper limit of the constant viscosity region. [Russian] English abstract. Author

56. Elastic constants of silver and gold. J. R. NEIGHBOURS and G. A. ALERS, *Phys. Rev.*, 1958, **111**, 707–712. Scientific Laboratory, Ford Motor Company, Dearborn, Michigan. The three elastic constants C_{44}, $\frac{1}{2}(C_{11}-C_{12})$ and $\frac{1}{2}(C_{11}+C_{12}+2C_{44})$ have been directly measured for silver and gold in the temperature range between 4·2 and 300°K. The various contributions to the values of the 0°K constants are analysed in terms of a simple model which quite successfully describes copper. It is concluded that such a model is unsatisfactory when applied to the heavier noble metals because these appear to have large non-central forces contributing to their constants. Combined with pressure data the present results show the elastic constants to be explicit functions of temperature. The Debye characteristic temperatures calculated from the 0°K elastic constants are shown to be in substantial agreement with the results from calorimetry. Author

57. Pressure derivatives of the elastic constants of copper, silver and gold to 10,000 bars. W. B. DANIELS and C. S. SMITH, *Phys. Rev.*, 1958, **111**, 713–721. Case Institute of Technology, Cleveland, Ohio, U.S.A. The pressure derivatives of the elastic constants of the homologous series of metals, copper, silver and gold have been measured over the pressure range from 0 to 10,000 bars, using a modified ultrasonic pulse-echo method. Means have been devised to measure the change of elastic constant with pressure as directly as possible. The values found for the pressure derivatives of the elastic constants are as follows :

	Cu	Ag	Au
dB/dP	5·59	6·18	6·43
dC/dP	2·35	2·31	1·79
dC/dP	0·580	0·639	0·438

The notation $C=C_{44}$, $C'=(C_{11}-C_{12})/2$ and $B=(C_{11}+2C_{12})_s/3$ has been used. The data for each metal, of the three elastic constants and their pressure derivatives, have been interpreted in terms of conventional theory. The theoretical contributions of long range interactions have been subtracted off and the remainder attributed to short-range nearest-neighbour interaction. The analysis indicates that these must be non-central, many-body interactions in order to account for the shear constants and especially their pressure derivatives. The many-body character of the interactions is of rapidly increasing importance in the sequence copper, silver, and gold. Author

58. Elastic constants of zinc from 4·2°K to 77·6°K. C. W. GARLAND and R. DALVEN, *Phys. Rev.*, 1958, **111**, 1232–1234. Department of Chemistry and Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Mass. The adiabatic elastic constants of zinc single crystals have been measured by an ultrasonic pulse technique. The values extrapolated to 0°K are : $C_{11}=1\cdot770$, $C_{33}=0\cdot685$, $C_{44}=0\cdot459$, $C_{12}=0\cdot348$, $C_{13}=0\cdot528$ in units of 10^{12} dyn cm^{-2}. A Debye characteristic temperature, θ, of 327°±5°K has been calculated at 0°K by averaging the inverse cube of the longitudinal and transverse elastic wave velocities over all directions of propagation. Author

59. Transient phenomena in the deformation of hot steel. C. ROSSARD and P. BLAIN, *Rheologica Acta*, 1958, **1**, 163–170. 185, Rue President Roosevelt, St. Germain-en-Laye (S&O), France. Stress as a function of strain at constant rate-of-strain is recorded for steel samples near 1100°C for both torsion and simple elongation. Stress at first rises to a maximum and then decreases to a more or less steady value. Photomicrographs showing changes of grain size and structure in cooled samples taken at different stages in the process are given. [French] A.S.L.

60. On the representation and extrapolation of creep data of metals and technical alloys. P. FELTHAM and J. D. MEAKIN, *Rheologica Acta*, 1958, **1**, 176–179. The University, Leeds. Creep and fracture data are given for a nickel alloy (Nimonic 90). Under constant tensile stress, a regime is reached in which elongation proceeds at a constant rate which is found to be inversely proportional to the time the specimen takes to fracture. A.S.L.

61. Behaviour of certain alloys subjected to dynamic loading. R. G. CRUM and F. T. MAVIS, *A.S.T.M. Bull.*, 1958, No. 231, 88–91. Carnegie Institute of Technology, Pittsburgh, Pa. A spring powered tensile impact apparatus is described giving a maximum velocity of 900 in.sec^{-1}, giving breaking times of about 1·5 msec. Stresses and strains measured by strain gauges and presented on cathode ray tubes were recorded simultaneously with the appearance of the specimen by the use of a high speed cine-camera. Yield stresses and ultimate strengths of steel, aluminium and titanium alloys were all higher for dynamic loading than for low speed testing. E.B.A.

62. Elastic constants of potassium iodide and potassium chloride. M. H. NORWOOD and C. V. BRISCOE, *Phys. Rev.*, 1958, **112**, 45–48. The Rice Institute, Houston, Texas. The sound velocities and elastic constants have been measured for pure single crystals of KI and KCl by the ultrasonic pulse technique over the temperature range from 4°K to 300°K. In KI, $C_{11}=3\cdot38$, $C_{12}=0\cdot22$, and $C_{44}=0\cdot368$ in units of 10^{11} dyn cm^{-2} at 0°K according to our extrapolations from 80°K. In KCl measurements of all three constants were made over the entire temperature range down to 40°K and their values at 0°K are $C_{11}=4\cdot83$, $C_{12}=0\cdot54$ and $C_{44}=0\cdot663$ in units of 10^{11} dyn cm^{-2}. The Debye characteristic temperature at 0°K, θ_0, has been calculated from these very low-temperature values of the elastic constants to give 129°±2°K for KI and 234°±1°K for KCl. The specific heats of KI, KCl and KBr have been calculated in this

paper by using a combination of a Debye and an Einstein term in the expression for the specific heat. These calculations indicate that the agreement between such a simple theory and experiment becomes better as the ratio of the ionic radii and masses increases in these three salts. We point out that in the four alkali halides thus far studied in this laboratory, there is evidence that the Cauchy relation $C_{12}=C_{44}$ is satisfied at about $T=\theta_0$. No reason is offered for this coincidence. Author

63. The correlation of internal friction and chemical structure in organic glasses. J. J. BENBOW and D. J. C. WOOD, *Trans. Faraday Soc.*, 1958, **54**, 1581, 1587. Imperial Chemical Industries Limited, Akers Research Laboratories, The Frythe, Welwyn, Herts. The internal friction of a number of organic glasses has been measured over a wide range of frequency. At the lower frequencies, the glasses are distinguished from one another by the extent to which the dependence of the internal friction on frequency conforms to the theoretical predictions for a Maxwell body. The frequency range over which this conformity is observed can be linked qualitatively with the effective size of the glass molecules, taking into account the existence of intermolecular association. At high frequencies the internal friction of each glass tends towards a definite, frequency-independent, value ; the magnitude of these values, when adjusted for the different viscosity characteristics of the glasses, can be correlated with the estimated degree of flexibility of the molecules involved. These conclusions apply also to the internal friction behaviour of high polymers. It is pointed out that the internal friction of a wide variety of materials under conditions where no appreciable viscous flow occurs exhibits a frequency-independent component. Author

64. Some observations on the dependence of strain on stress for ice. L. W. GOLD, *Canad. J. Phys.*, 1958, **36**, 1265–1274. Division of Building Research, N.R.C., Ottawa. Observations were made on the longitudinal and transverse strain of rectangular ice samples stressed at the rate of 2 kg $cm^{-2}sec^{-1}$ to a maximum stress of 10 kg cm^{-2}. The duration of the stress was kept less than 10 sec. Under these conditions the ice behaved elastically. The observations indicated that two deformation processes contributed to the measured strain. It is concluded that the two sources of strain are deformation of the grains and slip at the grain boundaries. Author

65. The influence of shear and rotatory inertia on the free flexural vibration of wooden beams. R. F. S. HEARMON, *Brit. J. Appl. Phys.*, 1958, **9**, 381. Forest Products Research Lab., Princes Risborough, Bucks. Shear and notatory inertia lead to a reduction in the frequency of flexural vibrations in beams as compared with that predicted by the simple treatment. Tables and graphs are drawn up to facilitate the estimation of a correction factor for " free–free " beams. Experiments are described where the frequencies of wooden beams are measured up to the 16th mode. Effects due to anisotropy in the wood are investigated. G.M.J.

66. Creep in wood. L. D. ARMSTRONG, *Timb. Tech.*, 1956, **64**, 527. A summary of tests made in the Division of Forest Products, C.S.I.R.O.,

Australia, on the effect of creep in ash-wood beams subjected to continuous loading in bending, compression, tension, and shear. Conclusions given. D.P.D.

67. The effect of adding hydrophilic plasticizer on the kinetics of structure-formation in the hardening of cement. E. E. SEGALOVA, R. R. SARKISYAN and P. A. REBINDER, *Kolloidnyi Zh.*, 1958, **20**, 611. Dept. of Colloid Chemistry, Faculty of Chemistry, University of Moscow. A study has been made of the effect of additions of the hydrophilic plasticizer SSB (Ca-lignosulphonates) on the structure formation and mechanical strength of the stone formed in the hardening of Portland cements with various tricalcium aluminate contents. It has been shown that the greatest lowering of the water/cement ratio and the highest increase in strength is achieved on utilization of cement mixtures in the induction period of structure formation, the latter being prolonged on the addition of SSB. Cement with high aluminate content may have a very short induction period of structure formation in the presence of the standard additions of SSB (0·2–0·3 wt.% of the cement), and the formation of the crystallization structure of the hydroaluminate will lead either to the formation of a quick setting cement or to a strong thickening of the mixture and increase in its water content. In plasticizing the cements with high aluminate content one must considerably increase the SSB-additions. This does not decrease the strength of hardened cement stone or concrete as the SSB-addition is completely sorbed by the newly formed aluminate hydration products during their crystallization. [Russian] English abstract. Author

Section D

POLYMERS, ELASTOMERS AND VISCOELASTIC MATERIALS

68. An instability in the flow of molten polymers. J. P. TORDELLA, *Rheologica Acta*, 1958, **1**, 216–221. Du Pont Experimental Station, Wilmington, Delaware, U.S.A. At high shear stress, the flow of molten polymers through capillaries results in irregularly-shaped extrudates. The critical flow rate (above which this occurs) is inversely proportional to the viscosity and is proportional to the cube of the capillary radius. Reynold's turbulence is therefore excluded as an explanation, but dimensional analysis shows that some elastic mechanism may be involved. As the critical flow rate is reached (from below), direct observation shows that the state of flow at the input end of the capillary becomes irregular ; fracture in this region is suggested as the cause of the extrudate irregularity. A.S.L.

69. A new method for measuring the two relaxation times of a viscoelastic liquid. ALI ABDEL KERIM IBRAHIM, *J. Chem. Phys.*, 1958, **28**, 1264–1265 (letter). Physics Dept., University of Alexandria, Egypt. Uses the Ibrahim relation (*J. Chem. Phys.*, 1953, **24**, 364) to determine λ_1 and λ_2, the two relaxation times from the experimental results of J. G. OLDROYD *et al.* (*Proc. Roy. Soc.*, 1951, **64**, 44.) on a solution of polymethyl methacrylate and pyridine. The constants are derived from the

slope and intercept of a line obtained by plotting the quotient of the dynamic viscosity and the dynamic rigidity against the inverse square of the angular frequency. E.B.A.

70. Cold-drawing of glass-like and crystalline polymers. J. S. LAZURKIN, *J. Polym. Sci.*, 1958, **30**, 595–604. Institute of Atomic Energy, Academy of Sciences of the U.S.S.R., Moscow, U.S.S.R. The isothermal and non-isothermal cold-drawing of glassy and crystalline polymers is discussed. The basic phenomena of cold-drawing are shown to be independent of local temperature rise. An expression is given, relating the initial stress to the rate of drawing, which holds for both crystalline and glassy materials. It is concluded that the activation energy for molecular rearrangement must decrease with increasing stress. [English] E.B.A.

71. The isothermal volume contraction of amorphous polymers. A. J. KOVACS, *J. Polym. Sci.*, 1958, **30**, 131–147. Centre de Reserches sur les Macromolécules, Strasbourg, France. The isothermal volume contraction which occurs when an amorphous polymer is quenched from a temperature above, to one below the glass transition temperature T_g, is described for a range of materials. The volume isotherm may be represented by a three-parameter function of the time $v=f(\log t')$ and the temperature dependence of the parameters is discussed. In the transition region the isotherms may be superposed by shifting along the log t' axis, and the variation of the shift parameter with temperature is similar to that obtained from viscoelastic studies. The discussion of the results leads to a precise kinetic definition of T_g compatible with that obtained by other methods. [French] E.B.A.

72. The tensile strength of polymers below the glass transition temperature. P. MASON, *J. Polym. Sci.*, 1958, **31**, 530–532. British Rubber Producers' Research Association, Welwyn Garden City, Herts, England. Tensile studies were made at −75°C on filled and unfilled samples of natural rubber and GR–S. The small effect of different filters and also of razor notches on the strength properties supports Buchdahl's contention that the strength of glassy polymers is not influenced by flaws, but is governed by a yielding criterion. The validity of Buchdahl's criterion, that the ratio of tensile strength to Young's modulus should be constant, was further verified by experiments at −190°C upon pre-stretched samples of natural rubber gum. E.B.A.

73. Elastic moduli in monolayers. N. W. TSCHOEGL, *J. Colloid Sci.*, 1958, **13**, 500–507. Bread Research Institute of Australia, North Sydney, New South Wales. The surface elastic moduli are the two-dimensional analogs of the elastic moduli in three dimensions. Experimental methods are reviewed briefly, and it is shown that Fourt's "elasticity index" for an oscillating vane or needle is dimensionally incorrect, whereas the formula proposed by TRAPEZNIKOV for an oscillating disc or ring is correct and can be derived exactly by regarding the film as an elastic annulus sheared in its own plane. A dimensionally correct formula is proposed for an oscillating needle as well as for an aperiodic needle type surface torsion pendulum. The relationships between the four two-

dimensional elastic constants of homogeneous isotropic films are derived and are shown to be different from the three dimensional formulae. The maximal value of the surface Poisson's ratio is unity instead of one half.
Author

74. Friction constants of chain molecules with excluded volume. W. H. STOCKMAYER and A. C. ALBRECHT, *J. Polym. Sci.*, 1958, **32**, 215–219. Dept. of Chemistry, Massachusetts Institute of Technology, Cambridge, Massachusetts, U.S.A. The validity of the Flory–Fox treatment of the friction constant is investigated for chains with excluded volume with the aid of theories due to Kirkwood and to Fixman. It is found that the effective hydrodynamic radius of a linear macromolecule is less affected by excluded volume than the radius of gyration and hence that the Flory–Fox number P should decrease slightly with increasing molecular weight or solvent power. E.B.A.

75. Response of linear high polymers to hydrostatic pressure. SHIRO MATSUOKA and BRYCE MAXWELL, *J. Polym. Sci.*, 1958, **32**, 131–159. Princeton University, Plastics Laboratory, Princeton, New Jersey, U.S.A. The bulk compressibility of linear high polymers was found to be a function of temperature, pressure and time. Polymer melts are highly compressible and structural changes (such as pressure induced crystallisation above the crystallite melting point) may be induced in some materials such as polyethylene. By pressurising and cooling a polyethylene melt a material of higher density, rigidity and crystallinity is obtained. The effects of bulk compressibility on the fabrication conditions and properties of plastics are discussed. E.B.A.

76. A new absolute molecular weight method for linear polymers. F. BUECHE and S. W. HARDING, *J. Polym. Sci.*, 1958, **32**, 177–186. Physics Dept., University of Wyoming, Laramie, Wyoming, U.S.A. By use of a previously derived theory, the absolute molecular weight of linear coiling polymers may be determined from the decrease in viscosity, with increasing rate of shear, of their concentrated solutions. The necessary data for such a determination may be obtained using a simple cone viscometer. The method was checked by comparing the results of measurements on samples of polystyrene and polymethylmethacrylate with values obtained from dilute solution viscosities, the agreement being satisfactory. For very wide molecular weight distributions the results are somewhat higher than the weight average. Since the method is only strictly valid for linear polymers it might be used to obtain useful information on the extent of branching in non-linear molecules. E.B.A.

77. Diffusion and viscosity measurements on macromolecules in solution. C. ROSSI, V. BIANCHI and V. MAGNASCO, *J. Polym. Sci.*, 1958, **30**, 175–186. Institute of Industrial Chemistry, University of Genoa, Genoa, Italy. Information regarding molecular dimensions and polymer-solvent interaction is derived from measurements of diffusion coefficients in polyoxyethylene–water and polystyrene–benzene systems. Since the molecular dimensions of high polymers are dependent upon the molecular expansion coefficient α, there exists at any given temperature an "ideal" solvent which will hold the molecule in an unperturbed configuration. A visco-

metric method for determining the composition of a solvent/non-solvent mixture which behaves ideally is described. Molecular dimensions and expansion coefficient at 34°C are derived for polystyrene fractions.
E.B.A.

78. Solution properties of branched dextrans. K. A. GRANATH, *J. Colloid Sci.*, 1958, **13**, 308–328. Institute of Physical Chemistry, University of Uppsala, and Research Laboratory Pharmacia Ltd., Uppsala, Sweden. The solution properties of two structurally different dextrans (a partially hydrolyzed native dextran and a fractionated clinical dextran) has been carried out to obtain a more complete picture of the hydrodynamic behaviour of branched polymer molecules. Measurements have been made on the viscosity, light scattering, sedimentation and other solution properties. Results have been compared with those of WALES *et al.*, SENTI *et al.* and OGSTON and WOODS. The effects of possible variations in the distribution of the branches along the chain and in the distribution of branch lengths has not been considered. R.B.B.

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79. Shear rate dependence of the viscosity and elastic compliance of polymer melts—Correspondence with a hydrodynamic theory of visco-elastic flow. R. H. BOYD, *J. Appl. Phys.*, 1958, **29**, 953–956. E. I. du Pont de Nemours & Co., Wilmington, Delaware. The variation of viscosity and elastic compliance with shear rate of several typical polymer melts has been measured. The results are compared with the predictions of a hydrodynamic flow theory proposed by Y. H. PAO (*J. Appl. Phys.*, 1957, **28**, 591). The agreement is satisfactory. Author

80. Crystallisation of elastic molecules of polymers. L. MANDELKERN, *Usp. Khim.*, 1958, **27**, 193. [Russian]

81. Denatured egg albumin—II. Viscosimetric studies on the aggregation of denatured egg albumin. H. SHIMOMURA and D. YONEZAWA, *J. Agric. Chem. Soc. Japan*, 1958, **32**, 426–430. [Japanese]

82. Tension of a polymer chain in a network. T. N. KHAZANOVICH, *Zh. tekh. fiz.*, 1958, **28**, 1441. [Russian]

83. The temperature dependence of flow curves. J. SCHURZ, *Rheologica Acta*, 1958, **1**, 261–264. Inst. für physikalische Chemie, Universität Graz, Austria. Using a capillary viscometer, complete flow curves are obtained for several polymer solutions of moderate concentration at different temperatures in the range of 10°C to 45°C. From the temperature dependence of various parameters (limiting " viscosities " at high and low shear rates, shear rate at the inflexion, etc.), associated " activation energies " are calculated in the usual way on the tacit assumption that the entropy of activation is zero. The question of correcting for non-uniform shear rate in the capillary is not considered. The difference of the " activation energies " (0·5 to 2 kcal mol^{-1}) so obtained for the limiting values of viscosity is attributed to the extension of the chain molecules, and the values for this difference are compared with literature data on lengths of the equivalent random link for the polymers concerned. [German] A.S.L.

84. Theory of dilute polymer solution—II. Osmotic pressure and frictional properties. M. KURATA and H. YAMAKAWA, *J. Chem. Phys.*, 1958, **29**, 311–325. Kyoto University, Japan. The intrinsic viscosity of polymers in solution is calculated following the Kirkwood and Riseman scheme allowing for intramolecular interaction of segments (excluded volume effect). The osmotic second virial coefficient is also calculated allowing for inter- and intra-molecular interaction. Results are compared with results for polystyrene in cyclohexane. E.B.A.

85. A network theory of constrained elastic recovery in concentrated polymer solutions. A. S. LODGE, *Rheologica Acta*, 1958, **1**, 158–163. British Rayon Research Association, Manchester, 22. The stress–strain–history relations of Green and Tobolsky, generalised to allow for a distribution of stress relaxation periods, are used to calculate the variation of normal stress components and the magnitudes of instantaneous and ultimate recovery in a liquid in a state of steady rectilinear shear flow when the shear stress is instantaneously made zero and the liquid is constrained so that the recovery involves only simple shear deformations. The transients associated with the start of shear flow are also considered. Inertial forces are neglected. A.S.L.

86. The effects of shape in streaming birefringence of polymer solutions. E. V. FRISMAN and V. N. TSVETKOV, *J. Polym. Sci.*, 1958, **30**, 297–314. The Physical Institute of the University of Leningrad, Leningrad, U.S.S.R. The use of the dumbbell theory for flexible polymer chains in solution, together with the optical model of an equivalent ellipsoid for the macromolecule leads to a theory of flow birefringence which takes account of the form effect for a wide range of shear rates. Data on polystyrene and *p-tert*-butylphenylmethacrylate in different solvents is presented. Good agreement with theory is found except for some polystyrene fractions in dioxane. A new effect—an anomalous dependence of orientation angle upon shear rate—is demonstrated and discussed. A simple theory of the concentration dependence of the form effect is proposed. E.B.A.

87. The optical study of flowing viscoelastic solutions. D. BOURGOIN, *Rheologica Acta*, 1958, **1**, 141–146. Institut Pasteur, Paris. A review is given of the data obtained in the author's laboratory for the variation with shear rate of viscosity, magnitude of flow birefringence, and extinction angle of the ternary system potassium laurate/potassium chloride/water for concentrations of 0·5 per cent to 20 per cent potassium laurate. It is argued that the data are qualitatively consistent with a model consisting of a suspension of asymmetric, deformable, particles. [French] A.S.L.

88. Concentration dependence of flow birefringence of polymer solutions. JEN TSI YANG, *J. Amer. Chem. Soc.*, 1958, **80**, 5139, 5146. Research and Development Division, American Viscose Corp., Marcus Hook, Penna. The extinction angle χ and birefringence increment $\Delta n/c$ of polymer at constant rate of shear D can be approximately related to the corresponding reduced viscosity η_{sp}/c by the expression $\cot 2\chi/\cot 2\chi_0 = (\Delta n/c)/(\Delta n/c)_0 = \eta_{sp}/c/[\eta]$ where the subscript zero refers to the intrinsic

value at infinite dilution. By relating $\eta_{sp}/c/[\eta]$ with Huggins or Martins viscosity–concentration equation it is possible to make a linear extrapolation of refringence data to infinite dilution. W.H.B.

89. On the question of the nature of relaxation of unvulcanized synthetic rubber mixes. K. VEBER, *Kolloidnyĭ Zh.*, 1958, **20**, 135. Central Labs. of the Tyre Industry, Fürstenwald, E. Germany. The relaxation times for rubbers are plotted on the basis of a Wiechert log-normal distribution, but an empirical formula is proposed :—

$$(S_0-S)/(S_0-S_\infty)=(t/\tau)^{\frac{1}{2}}$$

where S is stress t sec after constant strain is reached, S_0 is stress when $t=0$ and S_∞ and τ are empirical constants. The temperature variations of these constants are then related to the technological properties of the samples. [Russian] English abstract. G.W.S.B.

90. Some observations of the permanent set of cross-linked rubber samples after heating in a state of pure shear. D. NEUBERT and D. W. SAUNDERS, *Rheologica Acta*, 1958, **1**, 151–157. British Rayon Research Association, Heald Green Laboratories, Wythenshawe, Manchester, 22. Initially cross-linked samples are subjected to pure shear (involving elongation of linear elements parallel to $0x$, no change parallel to $0y$, and contraction parallel to $0z$, where $0x$, $0y$, $0z$ denote mutually perpendicular directions). In this state, the samples are heated in conditions known to result in the breakage of some cross-links and the formation of others. On cooling and releasing, the samples are found to elongate slightly but significantly in the direction $0y$. This elongation is about one third of that recently predicted on the basis of a " two-network " hypothesis due to Tobolsky. The permanent set in the Ox direction is in better agreement with this theory. It is suggested that the elongation in the $0y$ direction might be particularly sensitive to the form of stress-strain relation assumed for a " one-network " model. A.S.L.

91. Viscosity-equilibrium swelling correlations for natural rubber. G. M. BRISTOW and W. F. WATSON, *Trans. Faraday Soc.*, 1958, **54**, 1567, 1573. The British Rubber Producers' Research Assoc., 48–56, Tewin Road, Welwyn Garden City, Herts. A correlation is sought between the limiting viscosity numbers of a rubber sample in twenty-one solvents, and the equilibrium swellings of a cross-linked network of the rubber in the same solvents. The Flory–Fox treatment of viscosity and the Flory–Rehner treatment of swelling are applied to the data. The lack of knowledge of the variation with concentration of the polymer–solvent interaction parameter χ, which both theories involve, precludes a direct linking of these treatments. One set of data cannot therefore be accurately predicted from the other. However, trends in the variation of the parameter from good to bad solvents have been detected. The fairly regular change of viscosity with swelling found for the different solvents is interpreted and the question of using a concentration-dependent interaction parameter in the Flory–Rehner equation when applied to the swelling of the usual range of rubbers is considered. Author

92. Determination of the mechanical dynamic characteristics of rubber in the range of frequency of sound. V. P. VOLODIN, *Prib. Tekh. Eksp.*, 1957, No. 5, 86. [Russian]

93. A study of true flow and of high-elasticity of rubber and of synthetic rubber stocks. B. I. GENGRINOVICH and G. L. SLONIMSKII, *Kolloidnyi Zh.*, 1958, **20**, 143. Institute of Scientific Studies in the Tyre Industry, Moscow. The mechanical properties of tri- and multicomponent raw rubber mixes without vulcanizing agents have been studied by uniaxial compression deformation under constant load, resolving the deformation into the plastic and high elastic components. The values for the true viscosity and the high elastic modulus have been determined over the range 40–120° under different stresses and for different periods of deformation. The data obtained showed that considerable change in the structure of the mixes takes place under the action of forces and on heating. [Russian] English abstract. Author

94. Rupture of rubber—V. Cut growth in natural rubber vulcanizates. A. G. THOMAS, *J. Polym. Sci.*, 1958, **31**, 467–480. British Rubber Producers' Research Association, Welwyn Garden City, Herts, England. Cut growth in natural rubber gum vulcanizates has been studied using both steady and repeated loading. The results, obtained on two different types of test piece, are expressed in terms of a tearing energy concept previously advanced, and confirm experimentally a rupture criterion proposed in an earlier paper. Under repeated loading the initially smooth cut tip roughens progressively and the rate of growth decreases to a final steady value, and some consequences of this roughening are discussed. E.B.A.

95. High speed fracture in rubber. P. MASON, *J. Appl. Phys.*, 1958, **29**, 1146–1150. B.R.P.R.A., Welwyn G. C., Herts. Cinematographic observations have been made of crack propagation under well-defined boundary conditions in rubbers at speeds up to 30 m sec.$^{-1}$ The fracture-markings showed resemblances to those obtained with metals, plastics, and glass, and could be related directly to the corresponding speed of fracture-propagation. In close analogy with Schardin's observations on glass, a noncrystallizing rubber (GR–S) showed a mode of crack propagation in which the fractured surfaces were visually smooth and the speed was about one quarter of the speed of longitudinal elastic waves. A crystallizing rubber (natural rubber) did not show this mode of propagation under the present test conditions. It is suggested that the modes of solid fracture can be usefully classified in three categories : (i) slow propagation, generally with smooth surfaces, obtained by careful control of the boundary conditions ; (ii) propagation at intermediate rates with rough surfaces, involving correspondingly greater energy consumption ; and (iii) fast propagation with smooth surfaces, the rate of propagation being limited by the speed of elastic waves in the material in accord with Mott's theory. Author

96. Dependence of the ultimate properties of a GR–S rubber on strain rate and temperature. THOR L. SMITH, *J. Polym. Sci.*, 1958, **32**, 99–113. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California. Tensile properties of an unfilled GR–S rubber were measured with an Instron tensile tester at strain rates between $0{\cdot}158 \times 10^{-3}$ and $0{\cdot}158$ sec^{-1} and at temperatures from $-67{\cdot}8$ to $93{\cdot}3$°C. The tensile strengths and ultimate strains were each superposed to give composite

curves describing the properties as functions of a reduced strain-rate. The temperature dependence of the reduction parameter, obtained from the process of superposition, is essentially the same as is obtained by superposing the stress–strain curves (except at the extremes of temperature) and is given by the Williams, Landel and Ferry equation. The linear viscoelastic properties are represented by a reduced stress–strain curve. Ultimate properties at any strain-rate and temperature may be deduced from the results. E.B.A.

97. Nature of strain recovery in polyvinyl chloride following steady laminar shearing. W. F. O. POLLETT, *Rheologica Acta*, 1958, **1**, 257–260. Henley's Research Laboratories, Gravesend, Kent. The multi-network theory of Green and Tobolsky predicts that the instantaneous free elastic recovery of a polymer melt or solution, following steady shear flow, will involve, in addition to a simple shear, a contraction along the (previous) lines of flow and an isotropic expansion in planes normal to the lines of flow. A sample of plasticized PVC is sheared at 175°C for a specified time at a shear rate of 1 sec^{-1} in a cone and plate viscometer, is then cooled below 100°C without recovery being permitted and removed from the viscometer. Two sectors are cut from the sample and allowed to recover for 3 min at 185°C. This recovery involves a large contraction (up to 50%) along the lines of flow and an expansion in planes normal to the lines of flow which in some cases was not isotropic. Data obtained at different times of shearing, different temperatures, and from samples taken from different radial positions in the gap give similar results. As the time of shearing is increased, the magnitudes of the various components of recovery increase to maxima and then decrease. The magnitude of the shear component of recovery is also recorded. Control tests performed with the same temperature cycles but without shear flow give very much smaller dimensional changes than those mentioned above. The angle between cone and plate is 5° ; the state of flow is investigated by observing the deformation of a sample which has initially a narrow coloured sector. A.S.L.

98. The influence of formulation on the processing of P.V.C. compositions. R. HAMMOND, *Trans. Plast. Inst., Lond.*, 1958, **26**, 49. I.C.I. Plastics Division, Welwyn Garden City. The factors discussed include the effect of the size distribution and state of aglomeration of polymer particles on extrusion mixing, calendering and paste-spreading processes. In particular it is found that suspensions of very uniform sized polymer particles drop in viscosity at high shear rates as distinct from the dilatent behaviour of pastes made from polymers with particles of irregular shape and size. E.B.A.

99. Creep and stress-rupture behaviour of rigid P.V.C. pipe—2. J. H. FAUPEL, *Mod. Plast.*, 1958, **35**, 132–139, 202. Engineering Dept., E.I. du Pont de Nemours, Wilmington, Del. Presents results of tests on creep, stress–rupture and stress–relaxation of rigid P.V.C. pipe at 73°F. Tests were performed using internal pressure and longitudinal tension. A reasonably good correlation was found between observed bursting pressures and those calculated from tensile data. The rupture stress decreased linearly with the log of the time of stress application. E.B.A.

100. Rheological study of macromolecular substances—2. Rheological study of poly(vinyl chloride) pastes. Z. CSUROS, M. GROSZMANN, I. GECZY and K. JUHASZ, *Periodica Polytech.*, 1957, **1**, 203–215. [German]

101. Structure and rheological behaviour of polyvinylchloride plastisols. A. J. DE VRIES, *Rheologia Acta*, 1958, **1**, 274–280. Centre de Recherches de la Compagnie de Saint-Gobin, Antony (Seine), France. The viscosities of different samples of P.V.C., each plasticized with 40 per cent dioctylphthalate, are determined in a cone-and-plate viscometer at shear rates in the range 0·1 to 500 sec^{-1}. For four samples, as the shear rate is increased, the viscosity decreases steadily and becomes practically constant above 10 sec^{-1}; for one sample, the viscosity passes through a minimum and then increases. For this and two of the four samples, at a shear rate of 0·6 sec^{-1}, the viscosity increases rapidly from about 100 P to 500,000 P as the temperature is increased from 50°C to 100°C. The results are discussed in relation to structure. No yield point is observed at low shear rates. [French] A.S.L.

102. Mechanical relaxation phenomena in swollen cross-linked polystyrene. K. H. ILLERS and E. JENCKEL, *Rheologica Acta*, 1958, **1**, 322–330. Technische Hochschule, Aachen, W. Germany. Loss-factor data are given for lightly-cross-linked polystyrene samples, swollen to different amounts by three different swelling agents, for frequencies in the range 10^{-1} to 10^{4} c/s and temperatures in the range −130°C to 220°C. For the unswollen polymer, the absorption at 0·5 c/s has a high maximum (α) near 100°C, a low maximum (γ) near −120°C and an intermediate hump (β) near 20°C. With increasing amounts (up to 90%) of swelling agent, the α-maximum moves to lower temperatures, while the γ-maximum moves to higher temperatures and increases in height. The position of the γ-maximum is sensitive to the nature of the swelling agents used (diethyl-, dibutyl- and dioctyl phthalates). Some data are given for different degrees of cross-linking. [German] A.S.L.

103. The flow curves of polystyrene solutions. J. SCHURZ and K. H. SCHÄFER, *Rheologica Acta*, 1958, **1**, 264–268. Inst. f. physikalische Chemie, Universität Graz, Austria. A capillary viscometer is used to determine the flow curves of solutions in toluene of 7 samples of polystyrene (viscosity-average MWs in the range 21,000 to 900,000) at concentrations in the range 0·25 per cent to 10 per cent. The flow curves (log (mean shear rate) vs. log (maximum shear stress)) are much less curved than those for solutions of cellulose derivatives of comparable molecular weight. The inflexion points are indeterminate at the lower and concentration-dependent at the higher molecular weights. For 1 per cent solutions, the graph of log (shear rate at inflexion point) vs. log (average MW) is linear if the lowest molecular weight be excluded. The results are discussed in relation to the flexibility of polystyrene molecules. [German] A.S.L.

104. Structure of drawn polyethylene terephthalate. W. J. DULMAGE and A. L. GEDDES, *J. Polym. Sci.*, 1958, **31**, 499–512. Eastman Kodak Co., Rochester, New York. Measurements of birefringence, infra-red dichroism and X-ray diffraction have been made on crystallized and

uncrystallized films of polyethylene terephthalate stretched up to 500 per cent. High extensions produce high linear orientation of the molecular in the direction of stretch, with a tendency for the molecules to be parallel to the plane of the film. These orientations are enhanced by crystallization. At low extensions tilting of the crystalline regions occurs during crystallization so that in these cases the molecular axis of the crystallites takes up a preferred direction almost perpendicular to the direction of stretch. E.B.A.

105. Dynamic mechanical properties of polyethylene terephthalate. T. KAWAGUCHI, *J. Polym. Sci.*, 1958, **32**, 417–424. Research Dept., Toyo Rayon Co. Ltd., Otsu, Japan. Dynamic mechanical properties of polyethylene terephthalate were measured as functions of temperature from −70 to 310°C at 100–200 c/s by a cantilever vibration method. Two mechanical loss maxima are distinguished and their variation with crystallinity, orientation and water content of the material investigated. The low temperature loss process is compared in a series of polyesters. E.B.A.

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106. Effect of humidity on the dynamic moduli of nylon 6–6 monofilaments. B. A. DUNELL and J. M. R. QUISTWATER, *J. Chem. Phys.*, 1958, **29**, 450 (letter). Dept. of Chemistry, University of British Columbia, Vancouver. Absorption of water by 6–6 nylon results in a shift along the frequency axis of the curves of real and imaginary parts of the complex modulus. A master curve of frequency reduction factor against water content is the same for tests carried out at 35°C and 60°C and indicates the existence of a time–humidity superposition principle similar to the time–temperature superposition principle. E.B.A.

107. Dielectric dispersion in methacrylate polymers and its correlation with mechanical properties. J. D. FERRY and S. STRELLA, *J. Colloid. Sci.*, 1958, **13**, 459–471. Dept. of Chemistry, University of Wisconsin, Madison, Wisconsin. Recent measurements of the dielectric properties of a series of methacrylate polymers [ethyl to *n*-octyl] have provided data over a wide range of temperatures and frequencies. In this paper the data are examined with respect to the applicability of reduced variables, the calculation of relaxation spectra and comparison of the shapes of the latter as well as their temperature dependence with those of other dielectric spectra. Finally the results are compared with measurements of mechanical properties on the same materials and the general question of correlation of dielectric and mechanical properties is discussed.

108. Photoelastic properties of plasticized polymethyl methacrylate in the glassy state. J. H. LAMBLE and E. S. DAHMOUCH, *Brit. J. Appl. Phys.*, 1958, **9**, 388. Manchester College of Science and Technology. The stress optical coefficient of Perspex plasticised with dibutyl phthalate varies linearly from a negative value for the pure polymer to a positive value with 20 per cent by weight plasticizer, being zero with 10 per cent plasticizer. Another plasticizer, polyethylene glycol, was found to have a much smaller effect. Optical creep was found to reduce the value of the coefficients algebraically. Influence of plasticizer on refractive index and mechanical properties is also considered. G.M.J.

109. Correlation between dilatometric and viscoelastic data on a series of poly-*n*-alkyl-methacrylates. H. FUJITA and A. KISHIMOTO, *J. Colloid Sci.*, 1958, **13**, 418–428. Physical Chemistry Laboratory, Department of Fisheries, University of Kyoto, Maizuru, Japan. From the assumption that the glass transition temperature occurs at a state of iso-volume fraction of local free space a relation is first obtained from which the glass transition temperature of any member of a polymer series (polymers prepared from a homologous series of monomers) relative to the glass temperature of the first member, can be predicted from the change in specific volume of the two members, at a temperature corresponding to the glass temperature of the first member. A relation is assumed for the monomeric friction coefficient as a function of the average fractional free volume by analogy with the Doolittle equation as modified by Ferry and co-workers. By combining these two equations a relationship between dilatometric and viscoelastic data is obtained. Experimental data for a series of poly-*n*-alkyl-methacrylates (methyl to *n*-octyl) fit the expression satisfactorily. R.B.B.

110. Elastic and viscous properties of dilute solutions of poly(methyl)-methacrylate in certain solvent/non-solvent mixtures. B. A. TOMS, *Rheologica Acta*, 1958, **1**, 137–141. Courtaulds Ltd., Research Laboratory, Maidenhead, Berks. As the proportion of one non-solvent (water) in 3 per cent solutions of poly(methyl)methacrylate in pyridine/water mixtures is increased, there is a marked increase in the viscosity, stress relaxation period, " spinnbarkeit ", " Weissenberg effect ", and in the temperature dependence of viscosity. If the water is replaced by another non-solvent (*n*-heptane), these trends are reversed, with the exception of the change in stress relaxation period. As in earlier work, measurements of viscosity and (two) relaxation periods are made with a concentric cylinder viscometer used in steady rotation and in oscillatory rotation. A.S.L.

111. Viscometric behaviour of poly(methyl acrylate) in some solvents. N. T. SRINIVASAN and M. SANTAPPA, *Makromol. Chem.*, 1958, **27**, 61–68.

112. Effect of composition on the photo-elastic behaviour of methymethacrylate-diallyl phthalate (MMA–DAP) copolymers. KOZO KAWATA, *J. Polym. Sci.*, 1958, **32**, 27–31. Scientific Research Institute, Komagome, Bunkyo-Ku, Tokyo, Japan. The photoelastic behaviour of methylmethacrylate-diallyl phthalate copolymers was studied over a wide range of temperature and co-polymerisation ratio to determine the effect of cross-linking. Different kinds of dependence of the stress–optical coefficient upon temperature are observed for high (pure DAP), intermediate, and zero (pure MMA) degrees of chemical cross-linking respectively. The differences are most noticeable at temperatures above the glass transition. E.B.A.

113. The stiffness modulus of polyethylene as a function of temperature and structure. F. P. REDING, *J. Polym. Sci.*, 1958, **32**, 487–502. Research Dept. Union Carbide Chemicals Co., Division of Union Carbide Corporation, South Charleston, West Virginia, U.S.A. The stiffness moduli of polyethylenes covering a wide range of degree of branching and molecular

weight have been investigated from −150°C up to the melting points. The stiffness–temperature curves consist of (1) a region from −150 to −50°C in which the curves for all the materials coincide ; (2) a region from −50°C to the melting range in which the stiffness appears to be a function of density alone, except for very high molecular weights where the stiffness is higher than would be expected from the density alone ; and (3) the melting region in which the curves reflect the higher melting points of the more linear polymers. The stiffness–temperature curves exhibit no sharp glass transition such as is usually found in crystalline polymers. E.B.A.

114. The orientation of the crystalline and amorphous regions in polyethylene film. D. R. HOLMES and R. P. PALMER, *J. Polym. Sci.*, 1958, **31**, 345–358. Imperial Chemical Industries Ltd., Plastics Division, Welwyn Garden City, Herts, England. The orientation in the crystalline and amorphous regions of a series of tubular-extruded films of polyethylene have been studied by a combination of X-ray diffraction and optical methods. The preferred directions of the (*a*) and (*c*) crystallite axes depend on the extrusion conditions. A relation between the orientation angle and the optical birefringence has been established for a range of ethylene polymers. It is further deduced that in these films the amorphous material provides a small, nearly constant positive contribution to the birefringence irrespective of the crystalline contribution. Film crystallinities, calculated at some 45 per cent, are in good agreement with X-ray estimates. The results of the investigation are considered in reference to the manufacturing process. E.B.A.

115. The X-ray diffraction, birefringence and infra-red dichroism of stretched polyethylene—II. Generalized uniaxial crystal orientation. RICHARD S. STEIN, *J. Polym. Sci.*, 1958, **31**, 327–334. Dept. of Chemistry, University of Massachusetts, Amherst, Mass., U.S.A. A general method for describing the crystal orientation in a uniaxially oriented crystalline polymer is presented. It is shown that two orientation functions may be quantitatively evaluated from X-ray diffraction data. The variation of these during mechanical and thermal treatment may be studied. These functions are sufficient to completely characterize the crystal contribution to birefringence and infra-red dichroism, and the amorphous contributions may thus be inferred from a knowledge of the overall behaviour of the specimen. E.B.A.

116. The X-ray diffraction, birefringence and infra-red dichroism of stretched polyethylene—III. Biaxial orientation. RICHARD S. STEIN, *J. Polym. Sci.*, 1958, **31**, 335–343. Dept. of Chemistry, University of Massachusetts, Amherst, Mass., U.S.A. A set of functions for characterizing the crystal orientation in a biaxially oriented crystalline polymer is proposed. The additional orientation functions may be determined by measurement of the variation of X-ray intensity with tilt angle of a film. From these functions and those described in part II, the crystal contribution to the birefringence and infra-red dichroism of normal and tilted films may be calculated.

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117. The creep of low density polythene. E. A. W. HOFF, P. L. CLEGG and K. SHERRARD-SMITH, *Brit. Plast.*, 1958, **31**, 384. I.C.I. Ltd., Plastics Division, Welwyn Garden City. Creep under tensile stress was measured on polythene monofilaments extruded from polymers of melt flow indices of 0·2, 2 and 20, at temperatures from 20°C to 80°C in 5°C intervals. Four or more stress levels were used at each temperature. Circumferential creep of tubes of Grade 2 Alkathene was also measured at 20°, 30°, and 40°C under internal water pressure. "Working pressures" estimated from tensile creep experiments were somewhat lower than those estimated from the creep of the tubes under pressure. The relevance of this work to current published working pressures is discussed. E.B.A.

118. The change in density of low pressure polyethylene on stretching. F. A. BETTELHEIM and R. S. STEIN, *J. Polym. Sci.*, 1958, **31**, 523–525. Dept. of Chemistry, University of Massachusetts, Amherst, Mass., U.S.A. The apparent densities of polyethylene films, pre-stretched to varying degrees, were measured by the displacement method using in turn a liquid which swelled the sample and one which did not. The large fall in apparent density with increasing extension found only in the unswollen samples shows that vacuoles are formed on stretching the film, and supports the visual evidence of opacity. The slight drop in density with increasing extension in the swollen samples is attributed to the occurrence of a new crystal form in the extended film. E.B.A.

119. Rheological study of macromolecular substances—3. Viscometric determination of molecular weights of polyethylene. Z. CSUROS, I. GECZY, M. GROSZMANN and V. SPIEGEL, *Periodica Polytech.*, 1957, **1**, 217–221; *Magyar Kem. Folyoirat*, 1958, **64**, 166–167. [Hungarian] German summary.

120. Transitions in polytetrafluoroethylene. M. BACCAREDDA and E. BUTTA, *J. Polym. Sci.*, 1958, **31**, 189–191. Institute of Industrial & Applied Chemistry, University of Pisa, Italy. The mechanical dynamical properties of "Teflon" were determined over the range −180°C to 340°C at frequencies of 2 to 25 kc/s. The three transitions found (at −112°, −45° and 25°C) and the high temperature behaviour of the material are discussed. E.B.A.

121. The structure–viscosity of cellulose dissolved in cupriethylenediamine solution. W. LANG, *Rheologica Acta*, 1958, **1**, 248–250. Österreichische Stickstoffwerke A.G., Linz, Austria. Flow curves of solutions of cellulose of different average D.P. in the range 300 to 2100 and different concentrations in the range 0·1 per cent to 2·5 per cent were determined using a single capillary (Umstätter) viscometer. The shear rate at which the curve of log (mean shear rate) vs. log (maximum shear stress) shows an inflexion is found to decrease with increase of D.P., and to depend markedly on concentration at the higher D.P. The latter effect is attributed to aggregation. [German] A.S.L.

122. Investigations on the kinetics of viscose ripening. B. PHILIPP and H. DAUTZENBERG, *Faserforschung*, 1958, **9**, 507–321. Deutsche Akademie der Wissenschaften zu Berlin, Institut für Faserstoff-Forschung in Teltow-

Seehof, Germany. The course of viscose ripening is followed by measurements of spinnability i.e. the height of liquid thread which can be drawn up from a free liquid surface at a specified rate. The effect of adding a certain substance is to increase the spinnability from about 10 cm to about 20 to 30 cm. [German] A.S.L.

123. The degree of polymerization and its distribution in cellulose rayons —VI. The relation between the intrinsic viscosity and degree of polymerization of cellulose nitrate. W. G. HARLAND, *J. Text. Inst.*, 1958, **49**, T478. The British Cotton Industry Research Association, Shirley Institute, Didsbury, Manchester, 20. The relation between the intrinsic viscosity in *n*-butyl acetate and acetone and the degree of polymerization (D.P.) has been deduced for cellulose nitrate fractions with degree of polymerization in the range 100–1800 and nitrogen contents greater than 12 per cent. Cellulose trinitrates that had been fractionated three or four times were used, and the degree of polymerization was determined osmotically. A comparison of sedimentation (diffusion) and osmotic data for three nitrate fractions and seven fractions of cellulose acetate confirms that the fractions were reasonably homogeneous and justifies the relation of the intrinsic viscosity to the number average D.P. The data from previous papers in this field have been recalculated in a critical manner and the results compared with those of the present investigation. Author

124. Stabilization of viscose rayon by heat treatment. KISOU KANAMARU, NOBORU TOKITA and SUSUMU NOYAMA, *J. Polym. Sci.*, 1958, **31**, 359–382. Dept. of Chemical Engineering, Tokyo Institute of Technology, Ookayama, Tokyo, Japan. Viscose fibres, pre-swollen with dilute sulphuric acid of various concentrations, were heat treated at various temperatures between 60° and 200°C. The effects of this treatment upon modulus of elasticity, tensile strength, extensibility, crystallinity and water absorption, were examined. The optimum effects were obtained for acid pH of 3–5 and temperature of 60–70°C. The stabilization appears to occur by the growth of the crystalline regions. E.B.A.

125. Influence of temperature on the viscosity of gelatin solution. J. BENES, *Chem. Prumysl*, 1958, **8**, 331–334. [Czech.] English summary.

126. A note on the rubber-like properties of gelatin. D. W. JOPLING, *Rheologica Acta*, 1958, **1**, 133–137. Kodak Ltd., Wealdstone, Middlesex. Using suitable treatment by an alcohol–water mixture, formaldehyde-cross-linked gelatin gels are prepared having an extensibility (350 per cent) much greater than that previously obtainable (25 per cent). Load–extension curves for simple elongation agree well up to 300 per cent elongation with the predictions of the kinetic theory of rubberlike elasticity. Gelatin gels cross-linked with difluorodinitrobenzene have stable cross-links, and the load–temperature relation at constant elongation (50 per cent) is found to agree, in the range 50°C to 70°C, with that predicted by the kinetic theory. A.S.L.

127. Branching in polyacrylonitrile. LEIGHTON H. PEEBLES, Jr., *J. Amer. Chem. Soc.*, 1958, **80**, 5602, 5607. Research and Development Division,

The Chemstrand Corp., Decatur, Alabama, U.S.A. Intrinsic viscosity mol. wt. data reported for low mol. wt. fractions of a polyacrylonitrile–polyvinyl acetate copolymer containing less than 10 per cent vinyl acetate. W.H.B.

128. On some properties of polyacrylonitrile which appear in highly-viscous (spinning-) solutions. K. JOST, *Rheologica Acta*, 1958, **1**, 303–315. Badische Anilin-und Soda-Fabrik A.G., Ludwigshafen/Rhein, W. Germany. Viscosities of 20 per cent solutions in dimethylformamide of samples of polyacrylonitrile polymers having different molecular weight distributions do not vary systematically with the corresponding viscosities of 1 per cent. solutions ; these data are obtained using a rotation viscometer. The sol–gel transformation is followed by a falling-ball method and the associated structural changes are investigated by X-rays. [German] A.S.L.

129. Viscosity of formic acid solution of poly(aminotriazole). T. IMOTO and K. BANDO, *J. Chem. Soc. Japan, Chem. Sect.*, 1958, **61**, 598–600. [Japanese]

130. Polarisation-optical and mechanical investigation of the state of stress in macromolecular liquids for the case of Acronal 4 F. W. SCHÜRMANN, *Rheologica Acta*, 1958, **1**, 221–232. Institut für Mechanik, Techn. Hochschule, Aachen. A new concentric cylinder apparatus for the simultaneous measurement of viscosity and flow birefringence is described. The inner cylinder rotates, has guard rings at each end and a central portion mounted on a spring whose deformation is measured by a capacity transducer to give the torque ; the response time of the torque-measuring device is about 10^{-3} sec. The test liquid (Acronal 4F : a solution of polyacrylic acid butyl ester) is found to have a shear stress relaxation period of 0·17 sec. The outer cylinder radius is 5 cm. Using a 1 mm gap between cylinders, values of shear stress, magnitude of flow birefringence and extinction angle are given for shear rates in the range 1 to 10 sec^{-1} and temperatures in the range 16°C to 27°C. Using a 10 mm gap, as the shear rate is decreased from 0·35 to 0·05 sec^{-1}, the unusual result is found that the extinction angle increases above 45°, values up to 60° being observed. These results are discussed in terms of a tacit but questionable assumption that stress and refractive index tensors have the same principal directions. On first shearing a fresh sample, an increase of volume is observed and attributed to an alteration in packing of the polymer molecules. When the liquid is sheared for some time at a lower temperature, Schlieren patterns are observed in the gap. [German] A.S.L.

131. Creep characteristics of laminated epoxy plastics. J. DELMONTE, *Plastics Tech.*, 1958, **4**, 913. Furane Plastics, Los Angeles, Calif., U.S.A. The creep characteristics were measured by a cantilever method at a maximum fibre (reinforcement) stress of 10,000 p.s.i., the creep being the deformation after a standard period of loading and recovery. The effects of curing time and temperature and of hardener and diluent contents are shown graphically. E.B.

132. The choice of resilient materials for antivibration mountings. J. C. SNOWDON, *Brit. J. Appl. Phys.*, 1958, **9**, 461. Imperial College, London. The criteria defining a good antivibration mount material are studied. It is concluded that the material should possess a high damping factor and a dynamic modulus which do not increase greatly with frequency. Results of transmissibility measurements indicate that most high damping synthetic rubbers possess dynamic moduli which increase rapidly with frequency. Filled butyl rubber is an exception and affords superior isolation. G.M.J.

133. Plastics as solid lubricants and bearings. A. J. G. ALLAN, *Lubric. Engng.*, 1958, **14**, 211–215. E. I. du Pont de Nemours & Co. Inc., Wilmington, Delaware. Recent studies on the fundamental aspects of friction and wear of plastics are reviewed with particular reference to polytetrafluoroethylene (P.T.F.E.). It is suggested that differences reported in the friction of P.T.F.E. may be related to differences in the mechanism of shearing at the areas of intimate molecular contact. The wear of P.T.F.E. depends markedly on conditions of load and speed and the presence of fillers. It is possible that these differences in wear are related to the differences in friction. (From author's summary).

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Section E

PASTES AND SUSPENSIONS

134. The propagation of ultrasonics in suspensions of liquid globules in another liquid. P. A. ALLINSON and E. G. RICHARDSON, *Proc. Phys. Soc.*, 1958, **72**, 833–840. King's College, Newcastle-upon-Tyne. In continuation of earlier work, measurements have been made of the attenuation of ultrasonics in a liquid containing globules of another liquid in suspension, viz. an emulsion. The effect of the viscosity of the continuous liquid and of the mean size of the globules of the other liquid on the attenuation is investigated and tested against a theoretical formula. It is shown that besides viscous loss relevant factors are (1) scattering of the radiation out of the direct beam, (2) pulsation of the globules. Author

135. Statistical methods in the mechanics of granular bodies. J. LITWINISZYN, *Rheologica Acta*, 1958, **1**, 146–150. Polish Academy of Sciences, Cracow. The subsidence of a bed of sand is treated mathematically by assuming that the subsidence at one level is related to the subsidence at a lower level by an operator which is taken to have certain superposition and other properties. Predictions are compared with data obtained from experiments made with a model bed of dry sand of uniform grain size. A.S.L.

136. Exploratory study of the flow of granules through apertures. R. L. BROWN and J. C. RICHARDS, *Fluid Handling*, 1958, 289. British Coal Utilisation Research Association. Measurements were made on the flow of dry granular materials through orifices in the bases of cylindrical

vessels. The effects of orifice size and shape, particle size and shape, head of granular material, roughness of cylinder walls and particle packing are considered. Flow from wide vessels could be represented by the equation

$$\Delta = \beta(H/K) \exp(-\gamma H/K)$$

where $H = 4$ Area/Perimeter of orifice and $\Delta = Q/\rho A(gP)^{-\frac{1}{2}}$

(From abstract of paper read at a meeting of the Institution of Chemical Engineers, Oct. 21st, 1958). E.B.

137. Effect of capillary length to diameter ratio on grease viscosity. W. R. MILLER, T. J. WALSH and R. R. SLAYMAKER, *Lubric. Engng.*, 1958, **14**, 216–220. Case Institute of Technology, Cleveland, Ohio. One lithium and six sodium base greases were tested in capillaries of the same bore but different lengths. Shear stress and rate of shear at the wall were calculated using MOONEY's (1931) equations. For all the greases at 75°F the apparent viscosity at given rates of shear decreased as the length : diameter ratio of the capillaries increased from 40 to 250. For only one of the greases was the effect still evident in longer capillaries. Reducing the temperature increased the viscosity change. J.F.H.

138. Flow properties of lubricating oils under pressure. S. J. HAHN, H. EYRING, I. HIGUCHI and T. REE, *N.L.G.I. Spokesman*, 1958, **22**, 121–128. University of Utah. The flow properties of lubricating oils under pressure are described in terms of two kinds of flow units. Newtonian and non-Newtonian units. The increase in viscosity and non-Newtonian character with pressure are explained by the following two assumptions (1) the transition Newtonian unit — non-Newtonian unit, is induced at high pressures ; (2) the relaxation time increases with pressure. By introducing the above ideas into the Ree–Eyring theory of non-Newtonian flow, a new flow equation is derived, which is successfully applied to the flow of sperm oil, SAE 30 motor oil, lard oil, castor oil, naphthenic petroleum, paraffinic petroleum, and synthetic lubricant (di-(2-ethylhexyl)sebacate) under pressure. The effect of pressure on grease is considered, and the theory that the network of soap fibres is destroyed under pressure is proposed. [From authors' abstract].

139. Basic factors in the formation and stability of non-soap lubricating greases—I. A study of the factors responsible for gel formation. G. J. YOUNG and J. J. CHESSICK, *J. Colloid Sci.*, 1958, **13**, 358–371. The Surface Chemistry Laboratory, Lehigh University, Bethlehem, Pennsylvania. The oil-thickener interface was recognized as the seat of important properties in non-soap greases. In order to index the nature and extent of this interface, in a variety of systems, first the surface characteristics of several thickening agents and the physical properties of several oils were measured. These properties of the oils and solids were correlated with the behaviour of grease systems formulated from them. Modification of the interfacial region by water and its effect on grease building by inducing flocculations was then investigated. For hydrophobic thickeners, grease building efficiency depends directly on surface area for those above 200 m^2g^{-1}, and falls off sharply for thickness

of lower surface area. The amounts of thickeners required to give greases of a specified consistency vary as the square of their surface areas. For hydrophilic thickeners the amounts of water absorbed at the oil–thickener interface can be much larger than for hydrophobic thickeners and, indeed, control the consistency. Temperature, relative humidity, and amount of working of the grease affect the amount of water at the interface. The polarity of the oil has little effect on the grease building by hydrophobic thickeners, but greatly affects those built with hydrophilic thickeners. In the latter case, water enhances thickening in non-polar vehicles but somewhat surprisingly thins those made with polar, water-miscible oils. Author

140. Basic factors in the formation and stability of non-soap lubricating greases—II. The mechanism of gel formation. J. J. CHESSICK, A. C. ZETTLEMOYER and G. J. YOUNG, *J. Colloid Sci.*, 1958, **13**, 372–382. The Surface Chemistry Laboratory, Lehigh University, Bethlehem, Pennsylvania. High area hydrophobic and hydrophilic solids flocculate in pure or dry liquids to form grease gels by particle-to-particle contact. In these systems, particle diameter and concentration of thickener are more important in gel formation and resulting consistency than the degree of polarity of the solid surface or of the liquid. When water is present, on the other hand, the formation of structure depends greatly on whether the dispersed solid is hydrophilic or hydrophobic. Trace water markedly influences the flocculation of hydrophilic solids dispersed in polar or non-polar vehicles ; however, trace water has little effect on the flocculation process of hydrophobic thickeners. In non-polar vehicles, water enhances the flocculating ability of polar solids ; in polar vehicles the opposite effect is found. Heptyl alcohol and amine (and their benzene analogs) drastically thin greases built with polar solids. Heptyl aldehyde, chloride, and acids generally have small influence. As the polarity of the solid is increased, the thinning ability of the additives increases. Distinctly different are carbon black built greases which are not influenced by these additives. Greases built with Estersil which possess a predominantly but not entirely hydrophobic surface, are affected somewhat differently from the greases made from predominantly polar solids. In the presence of additives and water, the degree of surface polarity determines whether one component (water or additive) will be displaced by increasing concentrations of second component. Author

141. Rheology of plastic fats. M. VAN DEN TEMPEL, *Rheologica Acta*, 1958, **1**, 115–118. Unilever Research Laboratory, Vlaardingen, The Netherlands. Model compounds are formed by rapid cooling of solutions containing 15 per cent and 25 per cent of glyceryl tristeareate in paraffin oil. Torsional creep and recovery experiments are performed on samples in the form of hollow cylinders ; shear stress is measured as a function of time at constant shear rate for other samples, using a concentric cylinder viscometer. Data are interpreted qualitatively in terms of cracks produced in a network containing different kinds of junction points ; in some cases, visible cracks occurred in the samples. A.S.L.

142. Entrance effects in capillary flow of aluminium dilaurate–Toluene gels. W. H. BAUER, N. WEBER and S. E. WIBERLEY, *J. Phys. Chem.*,

1958, **62**, 1245. Rensselaer Polytechnic Institute, Troy, N.Y., U.S.A. At nominal wall rates of shear, D, above 100 sec in^{-1} a region of shear rate thinning, capillary flow of gels of 2 per cent aluminium dilaurate in toluene occurred with marked dependence of the flow curve (wall shearing stress, τ, vs. D) upon the radius-to-length ratio, R/L, of the capillary used. Large entrance effects were found. From plots of shearing stress required to give constant rate of shear vs. R/L for various shear rates, values of the shear stress, τ_0, corrected for entrance effects were obtained by extrapolation to $R/L=0$, and the flow curve D vs. τ_0 was drawn. The flow curve D_{real} vs. τ_0 was constructed after measurement of $d(\log D)/d(\log \tau)$. In the region of shear rate thinning a relation, $\tau^N=\eta^* D$, was found to apply, after correction for entrance effects. Author

143. The importance of the sigma phenomenon in the study of the flow of blood. G. W. SCOTT-BLAIR, *Rheologica Acta*, 1958, **1**, 123–126. National Institute for Research in Dairying, Reading. A brief review is given of explanations and data offered from 1836 to 1955 to explain the observation that, for certain liquids, the resistance to flow offered by capillaries of different diameter does not vary as the inverse fourth power of diameter as required by Poiseuille's relation. A.S.L.

144. Investigations of thixotropic suspensions with special reference to bentonite. H. ENNEKING, *Rheologica Acta*, 1958, **1**, 234–240. Institute für Mechanik, Techn. Hochschule, Aachen. In an attempt to resolve the discrepancies between published flow curves of bentonite suspensions, new measurements are performed with a concentric cylinder viscometer using different gap sizes (2 mm and 0·1 mm). Correction for variation of shear rate across the gap is made by a new procedure, necessitated by the occurrence of a minimum in the curve of shear stress vs. shear rate. The (corrected) flow curves are found to involve sharp discontinuities which depend on the gap size. Flow curves taken at different temperatures in the range 15°C to 65°C cross over one another. At high shear rates (6000 sec^{-1}), shear stress decreases with increasing temperature; at low shear rates (400 sec^{-1}), the opposite is the case. [German] A.S.L.

145. A rheological investigation on structured Askangel (bentonite) suspensions and of some of their derivatives. O. M. MDIVNISHVILI and G. V. VINOGRADOV, *Kolloidnyĭ Zh.*, 1958, **20**, 569. Caucasian Institute of Mineral Resources. Various bentonites have been studied in a rotation viscometer over a wide range of shear-rate. Flow curves are given and rheological constants are discussed in relation to base exchange. [Russian] English abstract. G.W.S.B.

146. On the rheology of concentrated dispersions. C. VAN DER POEL, *Rheologica Acta*, 1958, **1**, 198–205. Koninklijke/Shell Laboratorium, Amsterdam. The method of Fröhlich and Sack is used to calculate the elastic moduli of a suspension of elastic spheres in an elastic medium of different constants. For concentrations up to 60 per cent by volume, the results agree fairly well with existing data on the velocity of propagation of sound in suspensions of glass spheres in polymethyl methacrylate

and with newly reported data on the dynamic Young's and shear moduli of sand/bitumen mixtures obtained from the resonant frequencies for flexural and torsional vibrations of bars. A.S.L.

147. Recent developments in the engineering aspects of rheology. A. B. METZNER, *Rheologica Acta*, 1958, **1**, 205–212. University of Delaware, Newmark, Delaware, U.S.A. The state of knowledge of heat transfer, turbulent flow through tubes, and fluid agitation, for non-Newtonian fluids is reviewed. A.S.L.

148. Particle motions in sheared suspensions—VII. Internal circulation in fluid droplets (theoretical). W. BARTOK and S. G. MASON, *J. Colloid Sci.*, 1958, **13**, 293–307. Physical Chemistry Division, Pulp and Paper Research Institute of Canada, and Department of Chemistry, McGill University, Montreal, Canada. Equations are derived for the stream-lines inside and outside a viscous fluid sphere suspended at the origin of an infinite body of an immiscible viscous liquid which is undergoing plane-hyperbolic deformation using a set of equations for velocity components derived by G. I. Taylor. By means of a simple transformation, the same set of equations has been used to determine the stream-lines inside and outside a liquid drop undergoing laminar shear flow. Equations are also derived for the time of internal circulation for stream-lines close to the surface and near the center, respectively. Author

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149. Physico-chemical mechanisms of dispersed systems in ceramic technology. S. P. NICHIPORENKO, *Kolloidnyĭ Zh.*, 1958, **20**, 575. Institute for Building Materials and Products, Kiev. The study of the structural and mechanical properties of ceramic masses over a large range of shearing stresses, and of the process of moulding of these masses, from the standpoint of physico-chemical mechanics led to the proof of a number of assumptions and to the solution of several practical problems. The basic characteristics of the viscoelastoplastic properties: elasticity, plasticity and the true relaxation period may serve as criteria for evaluating the moulding properties of ceramic masses. They permit one to predict the behaviour of the masses in the process of moulding and shaping and point to ways for correcting any flaws in the properties. The studies lay down the theoretical basis for developing, shaping and moulding processes of ceramic masses. [Russian] English abstract.
Author (abridged)

150. On the structural-mechanical properties of clay suspensions used under difficult conditions of drilling. A. K. MISKARLI and T. T. GASANOVA, *Kolloidnyĭ Zh.*, 1958, **20**, 184. Chemical Institute of Azerbaidyan, Baku. The rheological properties of various drilling muds are discussed in relation to their chemical and mineralogical composition. [Russian] English abstract. G.W.S.B.

151. Physico-chemical principles for the control of mechanical properties of structures in clay-water systems. N. N. SERB-SERBINA, *Kolloidnyĭ Zh.*, 1958, **20**, 563. Dept. of Dispersed Systems, Acad. Sci. U.S.S.R., Inst. of Physical Chemistry, Moscow. The importance of layers of water mole-

cules between the points of contact of clay particles in both thick and thin suspensions is stressed. Steady-state creep, thixotropy and other rheological properties are determined by these layers. [Russian] English abstract. G.W.S.B.

152. The deformation characteristics of the natural and dispersed structures of certain types of clay. I. M. GORKOVA, *Kolloidnyĭ Zh.*, 1958, **20**, 585. Savarenskiĭ Lab. for Hydro-geological Problems, Acad. Sci. U.S.S.R. A comparative study of the mechanical properties of a number of clays, recent marine sediments and quick soils was made by determining the kinetics of strain development at several shear stresses and the viscosity–stress relationship. It was found that according to the binding forces between the particles and to the nature of their framework structure the clay soils may be classified as follows : (1) Quick-soils and the upper layers of recent marine sediments with high colloid and organic matter content have mobile, unstable structures with pseudoliquid and high-elastic properties and low viscosity. They are practically non-thixotropic. (2) Marine sediments and clays with loose coagulation structures have pseudosolid properties and high initial viscosity, but increase in stress causes rapid structural breakdown and a corresponding fall in viscosity. These soils are highly thixotropic. (3) The most dense and dehydrated Jurassic clays are pseudosolid and highly viscous, and show no appreciable thixotropy. They creep at slow rate of strain without pronounced rupture of structure, owing to residual hydrate layers between the particles. [Russian] English abstract. Author

153. Effect of electrolytes on the properties of clays. D. DELIC and A. GRIZO, *Tonindustrztg*, 1957, **18**, 220–223. Tests show that the viscosity and plasticity of clays show similar changes in relation to the electrolyte concentration, and that the regions of improved plasticity lie in the electrolyte concentration regions that also tend towards coagulation of the suspension. The viscosity was determined from 40 per cent suspensions and the bend strength was taken as the basis of plasticity. For this, specimens were prepared from clays that had already been investigated, with varying electrolyte concentrations. The effect of electrolyte was also studied on shrinkage at elevated temperatures. D.P.D.

154. On the rheology of peat preparation. D. SCHÜRING, *Rheologica Acta*, 1958, **1**, 194–198. Torfinstitut, Hannover. A N.W. German peat is represented as a Bingham body, and the effect of mechanical working in reducing the yield stress is considered. Effects of mechanical working in different screw extruders are investigated. [German] A.S.L.

155. The viscosity of dilute suspensions of thread-like particles. M. A. NAWAB and S. G. MASON, *J. Phys. Chem.*, 1958, **62**, 1248. Pulp and Paper Research Institute of Canada, and Department of Chemistry, McGill University, Montreal, Canada. The viscosity of dilute suspensions of thread-like rayon particles has been measured for various values of the axis ratio r, and the intrinsic viscosity α_0 compared with various theoretical equations. No good agreement with theory was found but evidence is presented to show that the intrinsic viscosity is sensitive to a mean particle-orientation factor which is in turn sensitive to permanent

and recoverable deformation of the particles by the velocity gradient, and that Burger's equations probably could be corrected for this effect so as to give agreement of a_0 with experiment. Suspensions of $r>113$ showed the Weissenburg effect, probably due to elastic deformation of the threads by the gradient. Author

156. Problem of concentrated suspensions (Rheological properties). D. RYSAVY, *Z. Phys. Chem., Lzg.*, 1958, **208**, 293–308. [German]

157. Coal preparation : The separation efficiency of dense medium baths. R. L. WHITMORE, *J. Inst. Fuel*, 1958, **31**, 422. University of Nottingham. Dense suspensions from a range of baths in coal dressing plants have been examined. All behave as Bingham fluids but the influence of the yield stress on the separation efficiency is much less than is supposed. From the experimental data, a tentative relationship between the separation efficiency and the plastic viscosity is proposed. G.M.J.

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Section F

LIQUIDS

158. Viscosity conversion nomograph. J. A. SEINER, *S.P.E.J.*, 1958, **14**, 23. Paint Research Department, Pittsburg Plate Glass Co. The nomograph enables the following viscosity units to be interconverted : Gardner-Holdt, Pratt-Lambert A & C, ASTM, Ford No. 4, Redwood Standard and Saybolt Universal. E.B.

159. The kinematic viscosity of liquid helium II. A. D. B. WOODS and A. C. HOLLIS HALLETT, *Canad. J. Phys.*, 1958, **36**, 1125–1126. Dept. of Physics, University of Toronto, Toronto, Ontario. A rotating cylinder viscometer has been used to study transient motions in liquid helium II. M.F.C.

160. Theoretical and experimental relaxation times of solutions. R. J. MEAKINS, *Proc. Phys. Soc.*, 1958, **72**, 283–286. Nat. Standards Lab., C.S.I.R.O., Sydney, Australia. Hill's equations, which are based on Andrade's model for the viscosity of a liquid, are used to calculate the relaxation times of solutions of a number of polar solutes in benzene and decalin solvents and the results are compared with experimental values and also with those obtained from Debye's equation. G.H.T.

161. The viscosity and density of benzene near its freezing point. P. M. HU and R. W. PARSONS, *Proc. Phys. Soc.*, 1958, **72**, 454–457. Physics Dept., University of Hong Kong. The object of the work was to determine whether there is any discontinuous behaviour at the freezing point as had been previously reported for phenyl ether and *m*-chlor-nitrobenzene. None was observed. In the equation $\eta=a\exp(c/T)$ the term c was found to depend on temperature. The results could be represented closely by an equation of the form $\log\eta=a+b/T+c/T^2$. G.H.T.

162. Germanium esters—II. Intermolecular forces and liquid structure. D. C. BRADLEY, L. J. KAY, J. D. SWANWICK and W. WARDLAW, *J. Chem. Soc.*, 1958, 3656, 3659. Birkbeck College, Malet Street, London, W.C.1. Viscosities are reported for esters of germanium $Ge(OR)_4$ with R = Me, Et, Pr^n, Pr^i, Bu^n, Bu^i, Bu^s, Bu^t from 20°C to 45° at 2·5°C intervals. The viscosities are Newtonian and the temperature coefficients in the relation $\log \eta = (c/T) - d$ are given. W.H.B.

163. Influence of the charge on the particles on the viscosity of sols. J. B. DONNET, *J. Polym. Sci.*, 1958, **30**, 651–659. Laboratoire de Chimie-Physique, E.S.C.M., Mulhouse, France. Experimental data is reported on the viscosity of colloidal suspensions of charged carbon particles. The results agree with current theories in respect of variables other than that of particle charge. Theory, however, predicts a strong dependence of viscosity upon charge whereas none is observed. [French] E.B.A.

164. The viscosity of dilute emulsions. M. A. NAWAB and S. G. MASON, *Trans. Faraday Soc.*, 1958, **54**, 1712, 1723. Physical Chemistry Division, Pulp and Paper Research Institute of Canada, Dept. of Chemistry, McGill University, Montreal. The viscosity of a series of dilute monodisperse oil/water emulsions having ratios of viscosity of disperse to continuous phases varying from 0·5 to 5·2 was measured as a function of emulsion concentration, and the intrinsic viscosity α_0 and the interaction coefficient α_1 were determined in the Newtonian region. It was concluded from these experiments that Taylor's theory was valid except when an interfacial film was formed by the emulsifying agent which tended to inhibit internal circulation. Oldroyd's recent extension of Taylor's theory was used to calculate a linear combination of the two-dimensional shear and dilatational viscosity coefficients of films causing deviation from Taylor's theory. When Taylor's theory applied, α_1 increased with increasing α_0 up to $\alpha_0 = 2{\cdot}5$ for rigid spheres according to a simple exponential relationship. When the system deviated from the theory, a more complicated relationship involving factors other than α_0 was indicated. W.H.B.

165. The viscosity of concentrated aqueous solutions of sodium chloride. C. V. SURVANARAYANA and V. K. VENKATESAN, *Trans. Faraday Soc.*, 1958, **54**, 1709, 1711. Physico-Chemical Laboratory, Annamalai University, Annamalainagar, S. India. The viscosities of aqueous solutions of sodium chloride from 1 molal to saturation and from 30° to 55°C are reported. W.H.B.

166. Changes in the speed of propagation of ultrasonic waves during transitions between liquid and solid states. K. GAMSKI, *Rheologica Acta*, 1958, **1**, 119–123. Université de Liège, Belgium. The possibility of using the speed of propagation of longitudinal ultrasonic waves as an index for liquid–solid transitions is considered, and data are given for the setting of paraffin wax and cements. [French] A.S.L.

167. Viscosities and surface tensions of some liquid halogen fluorides. M. T. ROGERS and E. E. GARVER, *J. Phys. Chem.*, 1958, **62**, 952. Department of Chemistry, Michigan State University, East Lansing, Michigan,

U.S.A. Values of the surface tension and viscosity of iodine pentafluoride, bromine pentafluoride and bromine trifluoride have been measured in the liquid phase over a range of temperature with a precision of ± 2 per cent and the data have been fitted to empirical equations. By application of the Eyring theory of viscosity, the heats and free energies of activation for viscous flow have been computed and are compared with the energies of vapourization. These results, along with the Trouton constants and the dielectric constants, indicate that iodine pentafluoride and bromine trifluoride are associated in the liquid phase, whereas chlorine trifluoride and bromine pentafluoride probably are normal. Author

168. Brittle fracture and spinnability of viscous materials. REMPEI GOTOH, HIROSHI AIDA, SOICHI HAYASHI and NISHIO HIRAI, *Rheologica Acta*, 1958, **1**, 213–215. Inst. for Chemical Research, Kyoto-University, Takatsuki, Osaka, Japan. Tension is measured as a function of extension at different rates of extension up to break for bitumens and for rosin/olive oil mixtures. For the latter, the temperature range was determined within which a liquid thread could be drawn upwards by a moving glass rod initially touching the liquid ; the results are considered qualitatively in terms of the effects of temperature changes on the values of viscosity and surface tension. A.S.L.

169. Viscous flow of liquids at constant volume and constant pressure. J. D. MACKENZIE, *J. Chem. Phys.*, 1958, **28**, 1037–1039. General Electric Research Laboratory, Schenectady, N.Y. The energy of activation for viscous flow at constant volume, E_v is dependent on the volume of a liquid. For normal liquids at elevated temperatures E_v is only a small fraction of the value of the activation energy at constant pressure E_p. However for associated liquids, on account of the presence of hydrogen bonds E_v is almost equivalent to E_p. It is suggested that in highly associated liquids like liquid silica and some molten glasses where flow necessitates the rupture of bonds of even greater energy, the difference between E_v and E_p should be negligible. Author

170. On a turbulent flow in the entrance portions of circular tubes. G. V. FILIPPOV, *Zh. tekh. fiz.*, 1958, **28**, 1923. [Russian]

Section G

GENERAL

171. The rheology of transitions. E. G. RICHARDSON, *Rheologica Acta*, 1958, **1**, 251–257. King's College, Newcastle upon Tyne, University of Durham. A brief review is given of selected topics e.g. the variation, near the sol–gel transition in a gelatine solution, of dynamic modulus and viscosity as determined from the attentuation and phase changes of shear waves ; the 1000-fold increase in the viscosity of molten sulphur with increase of temperature near 160°C ; and the changes with temperature of the velocity and absorption of sound in perspex, polystyrene and in certain binary liquid mixtures. A.S.L.

172. Flow and fracture. E. R. PARKER, *Metal Progr.*, 1957, **72**, 65–69 ; *Engng. Dig.*, 1957, **18**, 569–570. A review of theories of flow and fracture that have emerged slowly during the past twenty years. It is shown how these concepts can advance the development of new or improved materials, and provide a better understanding of the behaviour of those now in use. Dislocations, strain-hardening, creep, solution-hardening, hardening in two-phase systems, fracture, and non-metallic crystals (sodium and silver chlorides) are discussed. D.P.D.

173. Problems in predicting screw performance. L. D. BARR, *S.P.E.J.*, 1958, **14**, 52. Plax Corp. The predictions of three empirical equations relating extruder output rate with screw speed and dimensions and with the pressure and viscosity of the melt have been compared with experiment. A 3½ in. decreasing depth screw and polyethylene of melt index 2·0 were used. None of the equations agreed quantitatively with the experimental results but all appeared to be of the right form. E.B.

174. Viscosity equations for gas mixtures. W. E. FRANCIS, *Trans. Faraday Soc.*, 1958, **54**, 1492, 1497. Gas Council, Midlands Research Station, Wharf Lane, Solihull, Warks. A simplified relation between the viscosity of a gas mixture and the viscosities of the individual components is derived from the rigorous kinetic theory equations. The new relation appears to fit the known experimental data with an accuracy of about ±2 per cent and can be applied to mixtures containing a polar component. The equation has been tested on a large number of mixtures of gases of widely differing molecular weights and viscosities, involving considerable departures from the simple mixing rule. The limitations of various equations which have been proposed in the past are discussed, and it is shown that the new equation probably represents the best approximation possible with one of the Sutherland–Thiesen type.
Author

175. The rheological problem in chronic bronchitis. Further studies on the constituent mucoprotein and nucleoprotein. J. C. WHITE and P. C. ELMES, *Rheologica Acta*, 1958, **1**, 96–102. Dept. of Pathology, Postgraduate Medical School, London. In chronic bronchitis, the main cause of symptoms is the highly-viscous nature of certain secretions. The orientation of microfibrils present in these secretions is investigated using techniques of ultra-violet dichroism and of dispersion of (optical) birefringence. A.S.L.

176. Remarks on the elastic after-effect. J. KUBÁT, *Rheologica Acta*, 1958, **1**, 232–234. Swedish Wood Research Institute, Stockholm. A brief statement is given of the results of stress relaxation measurements at constant strain on a variety of metals, polymers, and paper. Stress is proportional to the logarithm of time elapsed from the start of relaxation ; the coefficient of proportionality is found to vary linearly with the value of stress at the start of relaxation. [German] A.S.L.

177. An experimental investigation into some problems connected with tackiness and adhesion. N. BRUNT, *Rheologica Acta*, 1958, **1**, 242–247. Central Laboratory, T.N.O., Delft, The Netherlands. A glass plate is

coated with a 30μ-thick film of a resin. A glass sphere of radius 2 mm is brought into contact with it, at constant rate of loading. The size of the contact region is measured. Data indicate that the time taken for the bodies to separate under a given pull depends on the magnitude of this pull and on the size of the contact region, but does not depend on the pressure applied and the time taken to build up the contact region. Some data are also given for diamond and steel spheres. A.S.L.

178. Prediction of pressure drop in grease distribution systems. E. F. KOENIG, E. M. JOHNSON and E. A. BANIAK, *Rev. Inst. Franç. Pétrole*, 1958, **13**, 289–308. Texas Oil Company, Beacon. See also N.L.G.I. Spokesman, 1956, **20**, 12. Using $\frac{1}{4}$ in., $\frac{3}{8}$ in. and $\frac{1}{2}$ in. copper pipe systems held at constant temperatures, pressure gradients and flow rates were measured for seven greases of medium to soft consistency. The data were used to calculate shear stress and mean rate of shear in the pipes. It was found that S.O.D. capillary viscometer data for the same greases did not agree with the pipe results. Thus, for a given mean rate of shear expected pipe pressure drop calculated from the viscometer data was between 15 and 25 per cent higher than that found in the pipe experiments. Nomographs for rapid estimation of pressure requirements in the three sizes of pipe and various types of fittings were then constructed from the pipeline data. [French] J.F.H.

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179. Progrès de la technologie du fromage. F. V. KOSIKOWSKI and G. MOCQUOT, *F.A.O. Publn. No.* 38, *Rome* 1958. Station Centrale de Recherches Laitiéres, Jouy-en-Josas, S. et O., France. Although this little book covers a much wider field than that of rheology, the twenty-six page section on rheological properties and methods of testing and the excellent bibliography make it well worth the attention of rheologists interested in dairy products. [French] G.W.S.B.

180. The effect of sucrose on gluten development and the solubility of the proteins of a soft wheat flour. ELMA J. BAXTER and E. ELIZABETH HESTER, *Cereal Chem.*, 1958, **35**, 366–374. Pillsbury Mills Inc., Refrigerated Foods, Research & Quality Control, Louisville, Ky., U.S.A.; Dept. of Foods & Nutrition, The Pennsylvania State Uny., University Park, Pa., U.S.A. Additions of 15 and 30 per cent sucrose (flour basis) to soft wheat flour increased dough development time in the mixograph. Sucrose levels of 60 and 120 per cent prevented dough formation; this was attributed to the competition between sucrose and the gluten proteins for water. Recovery of flour fractions by acetic acid extraction was not affected by the four concentrations of sucrose. Recovery of gluten protein diminished and soluble protein increased when sugar was present in the flour batter. The percentage of soluble protein extractable from gluten dispersions in water and sucrose solutions decreased with an increase in the protein concentration in the medium and increased with increases in sucrose concentration. Peptization was greater at 25°C than at 100°C. H.G.M.

181. A calculation of the shape of the alveograms of materials showing structural viscosity. A. H. BLOKSMA, *Cereal Chem.*, 1958, **35**, 323–330. Institute for Cereals, Flour and Bread, T.N.O., Wageningen, The Netherlands. Alveograms have been calculated for materials showing structural viscosity, assuming (1) that the dough bubble remains part of a sphere until rupture occurs, (2) that the volume of the dough bubble increases steadily, (3) that the dough is incompressible and (4) that every dough element constantly moves perpendicularly to the surface of the bubble at its place. From the resulting graphs it is concluded that, whereas Newton and Maxwell bodies cannot form spherical bubbles in the alveograph, a certain amount of structural viscosity probably favors the spherical shape of the bubble. According to data from the literature, the viscosity of a flour dough decreases faster with increasing rate of strain than is needed to approach the spherical shape most closely. The volumes at which the experimental alveograms attain their maximum heights, together with the sharpness of these maxima, indicate that flour doughs possess a relaxation time as well as structural viscosity. H.G.M.

182. Physical changes in milk caused by the action of rennet—III. Effects of separation, homogenization and pasteurization and of varying calcium contents on the rigidity moduli and viscosities of curd. G. W. SCOTT BLAIR and J. BURNETT, *J. Dairy Res.*, 1958, **25**, 457. National Institute for Research in Dairying, Shinfield, Reading. The rate of setting of curd is found to be approximately proportional, at any time, to the amount of still unset casein. Plots of all Burgers' parameters (immediate and slow elastic moduli, creep and damping viscosities) against log time give excellent straight lines from whose slopes and intercepts the effects of the various technological processes can be quantitatively described. Relaxation and retardation times are calculated and also their ratio, called the " springiness number ". The data were obtained by stressing a column of curd in a U-tube and they are compared with those from a commercial " torsiometer " in which alternating torsional stresses are applied. G.W.S.B.

183. Coalescence of liquid drops at oil–water interfaces. L. E. NIELSEN, R. WALL and G. ADAMS, *J. Colloid Sci.*, 1958, **13**, 441–458. Monsanto Chemical Company, Plastics Division, Springfield, Massachusetts. Measurements were made of the length of time single drops can exist at an oil–water interface before coalescence takes place with a bulk phase of the same composition as the drop. The effect of stabilising agents soluble in either the oil or water phases was investigated. Factors investigated included : (1) temperature, (2) size of drops and curvature of oil–water interfaces, (3) oil/water vs. water/oil drops, (4) kind of oil, (5) mutual solubility of oil and water phases, (6) type of stabilising agent, its concentration, pH, interfacial viscosity, and rigidity. R.B.B.

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Kolloidnyĭ Zh.
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Kunststoffe

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Neftyanoe Khoz.
NLGI Spokesman
Nuovo Cim.

Oil Ind., Moscow

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Further summaries of papers read at a Symposium on "Flow, Fatigue, and Failure" held by the British Society of Rheology in Leeds on 8–9 January, 1959.

Fracture, fatigue and yielding of materials as a stochastic process

By TAKEO YOKOBORI (Tohoku University, Japan)

Attempts have been made to interpret as a stochastic process the general features, especially the kinetic aspects, of many types of failure such as creep fracture of copper[1,2], fatigue fracture of steels[3–5], brittle fracture of steels[3] and glass[5–9] and yielding of mild steel. Temperature[5] and stress-rate dependence of fracture under various constant rates of stress application and stress and temperature dependence of time for fracture under various constant stresses[1,2,5] are well explained on the basis of this model. With regard to the yielding of mild steel[9–12], temperature and stress–rate dependence of the upper yield stress and the stress and temperature dependence of the delay time for the initiation of yielding under a rapidly applied constant stress are well explained[10–12] as a stochastic process based on present dislocation theory using three or four undetermined or physical constants.

The rate, μ, of failure occurrence per unit time can be determined experimentally from the observed scatter of the time for fracture[1–5]. For creep fracture of copper[1,2], μ is approximately related to applied constant stress, S, and absolute temperature, T, by the relation :

$$\mu = A \exp(\alpha S/RT) \qquad (1)$$

where A and α are constants independent of S and T. Equation (1) agrees formally with that of the rate in a rate process. Thus at least part of the experimentally observed scatter in fracture time under constant load or fracture strength may be identified with the randomness associated with thermal fluctuations in a rate process as which the stochastic process model mentioned above is regarded.

A similar trend is found in fatigue fracture[3–5] though the temperature dependence of μ in equation (1) has not yet been determined. The detailed model[13] is apparently inconsistent with the fact that there is very little or no stress frequency dependence for the usual low-frequency fatigue tests. This difficulty has been overcome by KEIRALLA[14] by assuming the number of cracks per unit time exceeding a critical size (μ in equation (1)) to be proportional to the number of cycles per unit time.

It is very interesting that the stochastic process model which disregards detailed atomic mechanisms can be applied reasonably to many types of fracture and failure of different metallic and non-metallic[15] materials. Since the validity of this model is well interpreted in terms of the atomic mechanism[9–12] for the yielding of mild steel, it would be very valuable to investigate the scatter characteristics of the delay time for the initiation of the yielding of mild steel under a rapidly applied constant stress to check whether equation (1) holds in this case or not.

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8. T. YOKOBORI, *J. Chem. Phys.*, 1954, **22**, 951.
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12. T. YOKOBORI, to be published.
13. T. YOKOBORI, *J. Phys. Soc. Japan*, 1955, **10**, 368.
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15. For high polymers see B. D. COLEMAN, *J. Appl. Phys.*, 1956, **27**, 862.

The tensile fracture characteristics of some aluminium alloys

By C. E. TURNER (Imperial College, University of London)

Most ductile materials when tested in simple tension at normal temperatures and speeds, show first an elastic region followed by a region of uniform reduction in cross-section and finally a region of local non-uniform straining, known as a neck. Most aluminium alloys fracture in this manner. Some, however, fracture without necking although experiencing a general uniform extension of perhaps 10 per cent, thus being not particularly brittle. The surfaces of such a fracture appear in many respects similar to the normal fracture after necking, and occur at approximately 45° to the axis of the test piece. Thus the question arises, why do some quite ductile aluminium alloys fracture in simple tension without necking, and with what other mechanical properties is this phenomenon associated.

Tensile tests have been made on some twelve major varieties of aluminium alloys, in various stages of heat treatment or cold work, on two different types of testing machine using either extensometer or autographic recorder. The object of these tests was to observe which alloys did not neck and whether such materials could be grouped according to other mechanical properties. It was speculated whether the absence of necking was in any way related to the discontinuous type of stress–strain curve often reported in the literature on tensile testing of light alloys. As the tests proceeded it became apparent that the details of these discontinuous curves were affected by the type of machine and recorder being used. Many previous workers have shown discontinuous yield curves where steps or serrations occur increasingly as the test

proceeds (this has been referred to as type B yielding). In general no distinction has been made between steps, Fig. 1, or serrations, Fig. 2.

FIG. 1

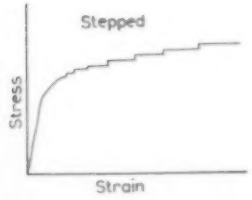
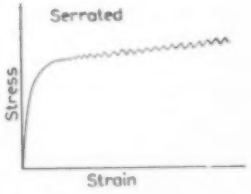


FIG. 2



It is evident that such a distinction can be made, although to what extent this represents an essentially different mechanism and to what extent it is influenced by the characteristics of the testing machine, is not clear. Both types of curve have however, been obtained on one machine so that the machine cannot be the only contributing factor.

Test pieces which did not neck showed a stepped curve, possibly followed by a serrated curve in the later parts of the test. Test pieces which did neck showed either smooth curves or wholly serrated curves. The fracture of non-necked test pieces was in all cases a shear type of separation at approximately 45° to the axis, and further correlations were found between the type of stress–strain curve and the appearance of the fracture—for example, only tests giving smooth curves showed a cup-and-cone fracture.

The generally accepted picture of ductile fracturing is briefly discussed in the paper, and compared with the observations made. It seems that, within the limited number of materials tested, the phenomenon of stepping plays some part in the onset of shear fracture without prior necking but the understanding of the real nature of these problems is very limited. The influence of machine characteristics on results and the likelihood of quasi-brittle fracture in service, of alloys which do not neck in simple tension, seem worthy of further attention.

Skeleton strength and critical porosity in set sulphate plasters

By K. K. SCHILLER (The British Plaster Board (Holdings) Ltd.)

The strength of set neat plaster can be described by means of two parameters which have been called the quality factor and the critical porosity. The former is a measure of the strength of the skeleton and depends on the type of test (compressive, tensile, etc.) whilst the latter characterises the pore system and is the same whatever the test under consideration. Neither depends on the actual porosity of the test piece (or the gauging water ratio).

In the present paper it is shown that these results can be extended to sand bearing plasters if the sand grains are regarded as " solid pores ".

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Both parameters increase linearly with the sand content but the critical porosity only very little.

The fact previously discovered by H. Andrews that the strength of sanded plasters is equal to that of the plaster matrix cementing the sand grains together has been confirmed with the materials used in the tests reported here.

In spite of the increase of the characteristic parameters with sand content plasters are in practice the weaker the more sand they bear. This is because more water has to be added with respect to the plaster to obtain the desired consistency. These results are derived graphically from a special representation of the experimental results.

Griffith's crack theory of brittle strength is shown to apply to the quality factor.

The work so far reported is restricted to rather pure plasters and special test sands of limited sieve range. The programme for further work is outlined.

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Section A

THEORETICAL

184. The characteristic method of solution for the problems of plane plastic strain. J. HALLING, *Engineer, Lond.*, 1959, **207**, 250–254. Technische Hogeschool, Afdeling der Weg-En Waterbouwkunde. The velocity and stress equations of plane plastic strain are hyperbolic linear partial differential equations. The article shows how the solution to such equations may be represented by series of characteristic curves which allow the determination of the stress and velocity conditions at all points in the deforming zone. The application of the method is demonstrated by its use in the study of the direct extrusion process. The theoretical solution for this process is compared with several results obtained experimentally using model materials whose mechanical properties approximate to the hypothetical plastic rigid material assumed in the theory. Author

185. Pseudo-plane state of shrinkage distortion in a non-homogeneous circular cylinder. Z. BYCHAWSKI and K. PISZCEK, *Arch. Mech. Stosowanej*, 1958, **10**, 211–233.

186. Free vibrations of system having one degree of freedom with non-linear elastic characteristic and non-linear viscous damping. S. ZIEMBA, *Arch. Mech. Stosowanej*, 1958, **10**, 163–194.

187. An investigation of the temperature stability of deformation distortions and the kinetics of friction surface recovery from strain hardening. K. V. SAVITSKY and M. P. ZAGREBENNIKOVA, *Dokl. Akad. Nauk SSSR*, 1958, **119**, 490–494. [Russian]

188. The stability of unhomogeneous elasticoplastic shells. E. I. GRIGOLUK, *Dokl. Akad. Nauk SSSR*, 1958, **119**, 663–666. [Russian]

189. Statistical mechanical theory of transport processes in liquids. F. C. COLLINS and HELEN RAFFEL, *J. Chem. Phys.*, 1958, **29**, 699. Dept. of Chemistry, Polytechnic Institute of Brooklyn, New York, U.S.A. The hydrodynamic equations of transport processes are developed so that irreversibility appear explicitly in terms of the instantaneous time derivatives of the stress in a molecular scale non-equilibrium region of a system otherwise at equilibrium. Shear and volume viscosity, and thermal conductivity coefficients may be obtained in terms of the hydrostatic pressure and the ideal heat of vaporization. E.B.A.

190. Criteria of validity of variational theorems in mechanics of inelastic non-homogeneous anisotropic deformable bodies. W. OLSZAK and P. PERZYNA, *Arch. Mech. Stosowanej*, 1958, **10**, 559–569.

191. Certain general formulae for plane circularly symmetric plastic states. M. ZYCZKOWSKI, *Arch. Mech. Stosowanej*, 1958, **10**, 463–479.

192. The problems of torsion and plane strain of non-homogeneous plastic bodies. A. I. KUUZNETZOV, *Arch. Mech. Stosowanej*, 1958, **10**, 447–463.

193. The inversion mapping as applied in the theory of plasticity. W. OLSZAK, *Arch. Mech. Stosowanej*, 1958, **10**, 417–441.

194. Relaxation phenomena in flow problems. A. STANIAWSKI, *Arch. Mech. Stosowanej*, 1958, **10**, 671–699. The problem is treated by Onsager's methods of the thermo-dynamics of irreversible processes.

195. Cracks in structural elements considered as a problem in the theory of elasticity and plasticity. W. OLSZAK, *Arch. Inzy. Ladowej (Warsaw)*, 1958, **6**, 131–167. [Polish]

196. The dynamical theory of plasticity as a link between the theory of elasticity and the theory of plasticity. J. MADEJSKI, *Arch. Inzy. Ladowej (Warsaw)*, 1958, **6**, 467–483. [Polish]

197. The damping of elastic vibrations in beams. J. WIECKOWSKI, *Arch. Inzy. Ladowej (Warsaw)*, 1958, **6**, 431–453. An analogy between the vibrations in elastic bodies and in liquids is pointed out and utilized in a study of simple cases of forced vibrations. [Polish]

198. Surface layer deformations due to sliding friction. A. S. RADCHIK and V. S. RADCHIK, *Dokl. Akad. Nauk SSSR*, 1958, **119**, 933–935. [Russian]

199. Unsteady flow with heat transfer in a viscous incompressible fluid between two rotating disks when there is injection of the fluid. G. A. TIRSKY, *Dokl. Akad. Nauk SSSR*, 1958, **119**, 226–228. [Russian]

200. Equilibrium of a viscoplastic disperse system on a rotating disk. A. M. GUTKIN, *Kolloidnyi Zh.*, 1958, **19**, 31–34. Molotov Institute of Power Engineering, Moscow. A relation between limiting radius and yield value is derived for a layer of a plastic medium in equilibrium on a rotating disk. [Russian] A.J.

201. Theory of the cone immersion method for determination of the yield values of disperse systems. N. N. AGRANAT and M. F. SHIROKOV, *Kolloidnyi Zh.*, 1958, **19**, 9–13. The S. Ordzhonikidze Institute of Aviation, Moscow. The mathematical theory of the cone plastometer is presented. [Russian]

202. The theory of flow of plastic disperse systems. N. V. TYABIN and G. V. VINOGRADOV, *Kolloidnyi Zh.*, 1958, **19**, 352–360. Institute of Petroleum, Academy of Sciences of U.S.S.R, Moscow. The flow of solidol greases as measured in capillary and rotational viscometers can be represented by a compound model of a Newtonian plus several Shwedoff–Bingham materials. [Russian] A.J.

203. Application of the method of approximations to calculations of flow of disperse systems. N. V. TYABIN and G. V. VINOGRADOV, *Kolloidnyi Zh.*, 1958, **19**, 505–510. Institute of Petroleum, Academy of Sciences of U.S.S.R., Moscow. The flow of plastic greases in sliding bearings and of bitumens along inclined planes has been used to demonstrate the necessity of evaluating actual values of the maximum tangential stresses and velocity gradients in approximating the flow curves for disperse systems. Flow of non-Newtonian fluids between coaxial cylinders and on an inclined plane is discussed. [Russian] A.J.

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204. Frictional losses of head in steady uniform flow. P. G. FRANKE, *J. Sci. Industr. Res.*, 1958, **17B**, 289–296. UNESCO Expert and Visiting Professor, College of Engineering, Poona, India. The known equations for the flow of liquids under streamline and turbulent conditions have been discussed and the application of equations, developed by Kármán–Prandtl, White–Colebrook, and Supino for determining the coefficient of resistance, when fluids flow under pressure through pipes and galleries, is explained. Based on the analogy of partly filled lines of circular cross-sections, formulae for flow in open channels are derived. A table of exponents used in these formulae is presented. Recent researches in the field have been reviewed and further lines of work are indicated. Author

205. Rheological computations of prestressed structures. C. EIMER, *Arch. Inzy. Ladowej* (*Warsaw*), 1958, **6**, 263–305. [Polish]

206. Investigations of the elastic properties of brick and of brick and slag-concrete walls. Z. GOLEBIOWSKI, *Arch. Inzy. Ladowej* (*Warsaw*), 1958, **6**, 229–256. [Polish]

207. Propagation of finite elastic waves in rubber. P. MASON, *Nature, Lond.*, 1959, **183**, 812–813, British Rubber Producers' Research Association, Tewin Road, Welwyn Garden City, Herts. On releasing one end of a stretched rubber strip, a finite pulse of unloading is propagated at constant velocity towards the fixed end. It is suggested that the velocity of the head of this pulse, which does not agree with the value predicted by the theory of James and Guth, is substantially the same as the velocity of longitudinal waves of infinitesimal amplitude. W.G.C.

208. Statistical mechanics of irreversible processes in polymer solutions, J. J. ERPENBECK and J. G. KIRKWOOD, *J. Chem. Phys.*, 1958, **29**, 909. Yale University, New Haven, Conn., U.S.A. A reformulation of the Kirkwood theory to include all contributions to the frictional forces on the monomer units. The calculations are applied to the intrinisic viscosity problem. E.B.A.

209. Some approximate equations useful in the phenomenological treatment of linear viscoelastic data. K. NINOMIYA and J. D. FERRY, *J. Colloid Sci.*, 1959, **14**, 36–48. Dept. of Chemistry, University of Wisconsin, Madison, Wisconsin. Two new approximation methods for the treatment of viscoelastic data are introduced. In the first, the relaxation (or

retardation) spectrum is obtained from several values of the real (or imaginary) component of the complex modulus (or compliance) without differentiation. In the second method the relaxation (or creep) formation is obtained by a very simple calculation from the real and imaginary parts of the complex modulus (or compliance). R.B.B.

210. Entanglements and other steric effects in crosslinked polymers. A. F. BLANCHARD and P. M. WOOTTON, *J. Polym. Sci.*, 1959, **34**, 627–649. Dunlop Research Centre, Birmingham, England. The modifications that must be applied to the kinetic theory of rubberlike elasticity to take account of the non-ideal nature of the molecular network, are discussed. Corrections are applied for molecular entanglements, chain stiffness and non-Gaussian distribution of chain length. The modified theory is applied to the relation between modulus and equilibrium swelling for natural rubber, and parameters representing steric hindrance and "solubility" are evaluated. E.H.A.

211. A diffusion theory of the viscoelasticity of rubbery polymers in finite elastic strain. M. MOONEY, *J. Polym. Sci.*, 1959, **34**, 599–626. Research Centre, United States Rubber Co., Wayne, New Jersey, U.S.A. The molecular mechanism of stress relaxation in a linear polymeric material is conceived of as a process of diffusion in phase space of molecular configuration. The analysis is an extension of Rouse's theory of linear visco-elasticity to finite, three-dimensional deformations. General expressions are derived which give the recoverable strains and the partial stresses at any instant of time. Particular cases treated are the tangential and normal stresses in continuous simple shear at a finite rate. E.H.A.

212. The Torque in Highly Twisted Nylon 6 Monofilaments. J. J. MERTENS, *J. Text. Inst.*, 1959, **50**, T70. N.V. Onderzochinginstituut Research, Arnhem, Netherlands. From theoretical considerations a method has been developed for comparing the torques in highly twisted filaments in such a way that effects due to changes in diameter of a fibre due to pretreatment can be separated from effects due to changes in molecular structure. The method involves the use of a "reduced torque" derived from the measured properties of the filament. Experiments are reported in which the effect of processes such as drawing and heat-setting under various conditions of time, temperature and tension are investigated. The results are discussed in terms of the theory. D.W.S.

213. The relation between birefringence and draw ratio of man-made fibres. H. DE VRIES, *J. Polym. Sci.*, 1959, **34**, 761–778. Central Lab. N.V. Onderzoekingsinstituut Research, A.K.U. and Affiliated Companies, Arnhem, The Netherlands. The relationship between birefringence (Δn) and draw ratio (λ) of several different polymer fibres can be expressed by a single empirical relation

$$d(\Delta n)/d(\ln\lambda) = m + p\Delta n$$

where m and p are constant characteristics of the particular fibre. No theory to account for the relationship has been forthcoming. E.H.A.

214 Correlation of sedimentation-rates by dimensionless groups. C. HARRIS, *Nature, Lond.*, 1959, **183**, 530–531. Dept. of Mining, University of Leeds, Leeds, 2. The method of using dimensionless groups to correlate data involving fluid flow has been applied to the study of sedimentation rates. By assuming plug flow, two equations can be derived which are used to relate data for the sedimentation of spheres and rough particles. W.G.C.

Section B

INSTRUMENTS AND TECHNIQUES

215. Capillary-tube viscometry with negligible kinetic energy effects. W. A. CAW and R. G. WYLIE, *Nature, Lond.*, 1958, **182**, 1153–1154. National Standards Laboratory, C.S.I.R.O., Sydney, N.S.W., Australia. Both U-tube and Ubbelohde-type capillary viscometers have been developed in which the kinetic energy effect is entirely negligible. This is achieved by forming a gradual flare, generally a few centimetres long, at each end of the capillary tube. Using these viscometers, conventional except for the flaring, at normal flow rates, it was found that the kinetic energy correction factor was reduced to less than 0·02. The factor increased uniformly with Reynold's number, and at a Reynold's number of 1000, was about half the usual value. W.G.C.

216. A rotational viscometer employing a reference liquid. J. F. HILLS, *J. Sci. Instrum.*, 1958, **35**, 415–418. Shell Refining Co. Ltd., Ellesmere Port, Cheshire. The viscometer described (Brit. Pat. App. No. 24561:57) employs a free rotor which is accelerated by the torque transmitted through a reference liquid by a driven rotor, and retarded by the torque acting through the liquid under test which is restrained by a stator. The free rotor thus obtains an equilibrium speed of rotation. The ratio of the rates of rotation of the driven and free rotors is a linear function of the viscosity being measured, and is independent of the absolute rotational speed of the driven rotor for Newtonian liquids. The theory of the viscometer is given together with an account of an experimental verification. For an instrument with a viscosity range of 1000 : 1 the maximum error does not exceed about $\pm 0{\cdot}5$ per cent of the measured viscosity for a single test. For error limits of $\pm 0{\cdot}2$ per cent the range is 30 : 1. Author

217. Controlling fluid processes with continuous viscometers. ALAN BEERBOWER, *Control Engng.*, 1958, **5**, 107–112. Esso Research & Engineering Co. This paper deals with the general problem of the continuous measurement and control of viscosity in industrial processes, and gives details of the instruments available in the United States. N.W.

218. Capillary viscometer for high temperature measurements of polymer solutions. G. D. PATTERSON, JR. and L. H. RABOUIN III, *Rev. Sci. Instrum.*, 1958, **29**, 1086–1088. Film Dept. Experimental Station, E. I. du Pont de Nemours & Co., Wilmington 98, Delaware. An all-glass capillary viscometer is described which permits dissolving polymers at high

temperatures, filtering, and measuring the solvent and solution efflux flow times without removal from a vapour bath. The advantages include safe handling of liquids at high temperatures without the precipitation or oxidative-degredation difficulties normally encountered in other methods of measuring polymer solution viscosities at elevated temperatures. Author

219. Rotation viscosimeter with a stroboscopic disc. K. REHACEK, *Chem. prumysl*, 1958, **8**, 365–366. [Czech, English summary]

220. Measurement of the falling velocity of particles in opaque fluids. V. FIDLERIS and R. L. WHITMORE, *J. Sci. Instrum.*, 1959, **36**, 35–36. Dept. of Mining and Fuels, University of Nottingham. An apparatus is described for the measurement of the falling velocity of small metallic or metal-coated particles through opaque fluids. An electromagnetic method of detecting the particles is employed. Particles of less than 1 mm can be detected. The limiting accuracy in the determination of the falling velocity is considered to be $\pm 0{\cdot}3$ per cent. W.G.C.

221. Calculation of the limiting shear stress (yield value) of disperse systems in experiments with the cone plastometer. N. N. AGRANAT and M. P. VOLAROVICH, *Kolloidnyi Zh.*, 1958, **19**, 3–8. The Moscow Peat Institute and the S. Ordzhonikidze Institute of Aviation, Moscow. The use of the cone plastometer for determining the yield point of lubricating greases is recommended. [Russian]

222. A systematic approach to the dynamic testing of high polymer solids. F. WINKLER, *Faserforsch.*, 1958, **9**, 476–484 ; 1959, **10**, 75–83. Textile Research Institute, Teltow-Seehof, Berlin. The different possible combinations of tests (elongation, tension, bending) are outlined ; 154 references to the literature are given. [German] A.S.L.

223. Measurement of dynamic surface tensions of aqueous solutions by the oscillating jet method. R. DEFAY and J. R. HOMMELEN, *J. Colloid Sci.*, 1958, **13**, 553–564. Université Libre de Bruxelles, Brussels, Belgium. The rate of surface tension lowering of aqueous solutions of ten long-chain alcohols and two dicarboxylic acids has been measured by the oscillating jet method. The surface tensions have been calculated by the Bohr formula. Seven orifices, standardized with water, have been used to determine the variation of surface tension with age for an aqueous solution of heptanol ($0{\cdot}4$ g/l). The results obtained, which lie on a right curve, are compared with published values. Author

224. Method of determining the dynamic constants of liquid-containing membrane manometer systems. R. J. LINDEN, *J. Sci. Instrum.*, 1959, **36**, 137–140. Dept. of Physiology, University of Leeds. An instrument with which to produce sine and square-wave changes in pressure in the hydraulic systems of membrane manometers is described. It consists of a cylindrical chamber to one end of which a metal membrane is secured ; fixed to the membrane is a strain gauge which, when energized by alternating voltages, causes alternating pressure changes in the chamber. The use of the instrument in the examination of a damped capacitance manometer system is described. Author

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225. Investigation of mixtures of coal tar with bitumen. K. KRENKLER, *Bitumen, Teere, Asph. u. Peche*, 1958, **9**, 271–274, 301–307, 335–340, 367–370. Stuttgart. An apparatus is described for the measurement of the strength of adhesion of a film of bitumen. Measurement is made of the force required to strip a 1 mm thick film from a glass plate at a rate of 5 cm per minute. Results are given for various mixtures of tars and bitumens followed by a discussion of their significance. [German]

J.F.H.

226. Measurement of adhesion by a blister method. H. DANNENBERG, *J. Polym. Sci.*, 1958, **33**, 509–510. Shell Development Co., Emeryville, California. Adhesion between a coating and substrate is measured by injecting a liquid between the two and recording the pressure at which blisters are formed. Reproducible results are obtained on clean substrate surfaces.

E.H.A.

227. Investigations on boundary friction and adhesion with the aim of gaining insight concerning the interaction of finely dispersed particles. I. On some boundary properties of solutions within narrow flat spaces between solid bodies. G. I. FUKS, *Kolloidnyi Zh.*, 1958, **20**, 748. Scientific Research Institute of Horology, Moscow. A method is described for measuring the distance between parallel plane disks $<0{\cdot}02\ \mu$ and the rates of their relative movements. Electrolyte solutions and surface-active compounds show abnormally high viscosities in such narrow spaces. Factors governing the thickness and rheological properties of these boundary layers are discussed. [Russian, English abstract]

G.W.S.B.

228. Continuous measurement of liquid density. A. LINFORD, *Indust. Chem.*, 1958, **34**, 481–488. Theory and constructional details of types of instrument are given. Comparator tube methods based on sampling or continuous flow methods are discussed in detail. For slurries and similar liquids weighing and buoyancy methods are more suitable. A gamma-ray absorption method is also briefly described.

R.B.B.

229. Design and operation of continuous thickeners. N. J. HASSETT, *Indust. Chem.*, 1958, **34**, 489–494. Dept. of Chemical Engineering, College of Technology, Loughborough. Cf. *Ind. Eng. Chem.*, 1958, **34**, 116, 169. Concentration gradients in batch settling of suspensions of finely divided fused alumina and precipitated chalk in water are examined both theoretically and experimentally. Results show that concentration gradients in the lower zone of a thickener are such that concentration levels remain stationary. Application of the results to continuous thickener operation is briefly discussed.

R.B.B.

230. A vibration pick-up which does not load the system being examined. S. K. RUSHWORTH and A. SELWOOD, *J. Sci. Instrum.*, 1958, **35**, 340–343. Wind Tunnel Dept., Bristol Aircraft Ltd., Bristol. The described apparatus measures the amplitude, and indicates the phase, of vibration of a structure without touching or loading it in any way. A moving-coil vibrator is held close to the structure and is electrically driven so that the vibrator oscillates in sympathy with, and without absorbing energy from, the structure. A proximity meter is used to measure the capacitance between

the structure and a pick-up electrode. The amplitude and phase of the current which drives the vibrator is then adjusted until this capacitance becomes constant. The apparatus, which is only suitable for the measurement of continuous simple harmonic oscillations (as in resonance testing), was used to measure vibration amplitudes up to 0·030 in., with good linearity and reproducibility and with a resolution of 1×10^{-4} in. The structure to be examined must either be metallic or have an electrically conducting layer. W.G.C.

231. A simple creep strain recorder for use with wire specimens. J. CONGLETON and R. N. PARKINS, *J. Sci. Instrum.*, 1958, **35**, 379–380. Dept. of Metallurgy, University of Durham, King's College, Newcastle upon Tyne. Earlier devices for measuring creep strain are mentioned. By a simple modification of the Martens principle an inexpensive recording extensometer has been developed which is capable of high sensitivity and of measuring large total strains. The method employs an optical lever device with recording on photographic paper. The difficulty of gripping the specimens has been overcome by upsetting the ends of the specimen into steel collets. W.G.C.

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232. A buckling string calibrator for thread strength machines. S. L. ANDERSON, *J. Sci. Instrum.*, 1958, **35**, 381–382. Wool Industries Research Association, Leeds. Static calibration of strength testing machines is not completely satisfactory, since any frictional and inertial forces exerted will be different from those experienced during actual dynamic testing. By bending steel test strips with curved cross-sections (similar to the strip seen in expanding steel rulers), the testing machine may be calibrated dynamically from the tension at which the strip buckles. It was found that the buckling tension was repeatable within 1 per cent and that it did not vary over the range of extension rates 0·5–200 mm/min (i.e. negligible inertial effects). Test strips have been constructed with buckling tensions ranging from 50 to 480 g. W.G.C.

233. A piezo-electric pressure bar gauge. D. H. EDWARDS, *J. Sci. Instrum.*, 1958, **35**, 346–349. Dept. of Physics, University College of Wales, Aberystwyth. A pressure bar gauge is described in which the average stress over the cross-section of the bar is measured by means of an X-cut quartz disk. Bars of duralumin and lead are employed since the acoustic impedances of these materials closely match the value appropriate to longitudinal thickness vibrations in the quartz. The design of the gauge housing, suitable for mounting in the wall of an explosion or shock tube, is discussed. Author

Section C

METALS AND OTHER SOLIDS

234. Metals and alloys above 1200°C. J. W. MARTIN, *Nature, Lond.*, 1958, **182**, 1418–1419. A brief report of a symposium with the above title, held at Oxford on 17–18 September, in part of which the mechanical properties at high temperatures were discussed. Papers described the determination of the creep properties of ceramics and high-melting-point

metals in air and *in vacuo*, and of the properties of refractory metals and their carbides up to 2500–3000°C. High-temperature mechanical working of molybdenum was discussed. Also a paper presented an extension of the simple theory of the thermal stresses in flat plates, so that variations with temperature and stress of the thermal and elastic properties of the material can be taken into account. W.G.C.

235. Abnormally high fatigue strengths in aluminium alloy extruded bar. J. M. FINNEY and J. Y. MANN, *Nature, Lond.*, 1958, **182**, 1366–1367. Aeronautical Research Laboratories, Australian Defence Scientific Service, Dept. of Supply, Melbourne, Australia. Unnotched and notched rotating cantilever fatigue tests at 12,000 cycles/min. have been conducted on two batches of aluminium alloy extruded bar. These show that the tension properties of both batches are far in excess of the specification properties of the alloys. Notched specimens, particularly those tested at high nominal stresses, tended to give a "conical" type of fracture. It is suggested that these abnormal characteristics may be linked with some peculiar extrusion texture. W.G.C.

236. Regularities in the plastic flow of lead and tin under clean shear. V. I. LICHTMAN and V. S. OSTROVSKY, *Dokl. Akad. Nauk SSSR*, 1958, **119**, 484–487. [Russian]

237. Stress corrosion cracking of Austenitic stainless steels with applied e.m.f. J. G. HINES and T. P. HOAR, *J. Appl. Chem.*, 1958, **8**, 764. Dept. of Metallurgy, Cambridge. The stress-corrosion cracking of chromium–nickel Austenitic stainless steel in 42 wt. per cent aqueous magnesium chloride solution at 150–154° saturated with air, has been studied under conditions of cathodic or anodic treatment of the metal during the induction period prior to crack initiation and/or during crack propagation. Part of Author's abstract

238. Brittle failure of single zinc crystals. V. I. LICHTMAN, L. A. KOCHANOVA and L. C. BRINKHANOVA, *Dokl. Akad. Nauk SSSR*, 1958, **120**, 757–760. [Russian]

239. An experimental study of the loading function for nickel specimens plastically prestrained by tension. Yu. I. JAGN and O. A. SHISHMAREO, *Dokl. Akad. Nauk SSSR*, 1958, **119**, 46–48. [Russian]

240. Elastic constants of α-brasses: room-temperature variation with solute concentration. J. A. RAYNE, *Phys. Rev.*, 1958, **112**, 1125–1130. Westinghouse Research Laboratory, Pittsburgh, Pennsylvania. Room-temperature elastic constant measurements have been made on a representative series of α-brasses. The variation with solute concentration of the shear constant C suggests that there is an appreciable contribution to it resulting from the onset of overlap between the Fermi surface and the [111] faces of the Brillouin zone. There is reasonable agreement between the experimentally determined magnitude of this contribution and that predicted from theory. According to the latter, there should be no corresponding contribution to the shear constant C', which prediction appears to be in accordance with experiment. Author

241. Tensile strength of indium. B. FULLMAN, *Nature, Lond.*, 1958, **182**, 862. British Non-Ferrous Metals Research Association, Euston Street, London N.W.1. With reference to the paper by EPPELSHEIMER and REITSMA *Ibid*, pp. 339–340 (see *Rheology Abstracts* 1958, **1**, No. 502) further data for the tensile strength and elongation of indium are quoted. W.G.C.

242. Mechanical resonance dispersion in quartz at audio frequencies. E. R. FITZGERALD, *Phys. Rev.*, 1958, **112**, 765–784. Dept. of Physics, The Pennsylvania State University, University Park, Pennsylvania. Measurements of the complex shear compliance of single crystals of quartz and fused quartz at frequencies from 100 to 5000 c/s have resulted in the discovery of sharp resonances in the compliances similar to those recently found in polycrystalline metals and crystalline polymers. The number, locations, and magnitudes of the resonances depend on crystal orientation with respect to the applied dynamic stress and vary with temperature, external static stress, and, in some cases, with time. An explanation of the resonances is suggested by some unpublished calculations of Fermi for non-linear systems in which no tendency towards equipartition of energy among modes is found. R.B.B.

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243. Attenuation of small amplitude stress waves in solids. L. KNOPOFF and G. J. F. MACDONALD, *Rev. Mod. Phys.*, 1958, **30**, 1178–1192. Institute of Geophysics, University of California, Los Angeles, California, U.S.A. The study of attenuation of stress waves demonstrates the failure of Hooke's law even at extremely small strains. In this paper the results of attenuation experiments on many materials are reviewed, and these indicate that over the frequency range 10^{-2}–10^{7} c/s, the specific dissipation function of inorganic, non-ferromagnetic solids is very nearly independent of frequency. This fact is shown to be probably attributable to non-linear permanent deformation, a theory for which is derived. The results of this theory are discussed with relation to the transmission of shear and longitudinal waves and of pulses. W.G.C.

244. Tensile strength of asbestos. R. ZOKOWSKI and R. GAZE, *Nature, Lond.*, 1959, **183**, 35–37. Central Research Laboratory, The Cape Asbestos Co. Ltd., Harts Lane, Barking, Essex. The tensile strengths and Young's moduli for several species of asbestos fibre are reported. Using very short fibres, tensile strengths of about 9×10^{5} lb/in^{2} were obtained. This value approaches that suggested by Orowan of 15×10^{5} lb/in^{2} for solids of this type. From high-speed photographs it appears that failure usually begins at a surface flaw, but that the strain is relieved by rupture of the relatively weak interfibrillar bonds. This produces broken fibres at that point, and exposes the surfaces of fresh fibres which may begin to fail at a different place. W.G.C.

245. Elastic deformation of wood. YU. M. IVANOV, *Kolloidnyi Zh.*, 1958, **19**, 293–298. Moscow. Large deformation (5–10 per cent) occurring when wood is compressed in the fibre direction in the second region are shown to be reversible and to have the characteristics of high elastic deformation in polymers. [Russian] A.J.

246. The effect of temperature of calcination of magnesite on the physical properties of Sorel cement. M. Rai and H. S. Vijayanath, *J. Sci. Industr. Res.*, 1958, **17A**, 318–320. Central Salt Research Institute, Bhavnagar, India. The effect of calcining Salem magnesite at 800°, 900°, 1000° and 1100°C on the properties of magnesium oxide samples produced and on the characteristics of magnesium oxychloride cement prepared from different oxide sources has been studied. It has been observed that the tensile, transverse and compressive strengths are the highest with MgO produced at 1000°C. W.G.C.

247. Strength and deformability of concrete under biaxial compression. J. Glomb, *Arch. Inzy. Ladowej* (*Warsaw*), 1958, **6**, 3–33. An experimental paper dealing with pre-stressed planar slabs. [Polish]

248. The effect of the mode of utilization of coarse aggregates on the strength of concrete. W. Kuczynski, *Arch. Inzy. Ladowej* (*Warsaw*), 1958, **6**, 181–211. An experimental study of the effect of aggregate dimensions on strength. [Polish]

249. Torsional vibrational experiments on rectangular concrete beams. R. Jones, *Brit. J. Appl. Phys.*, 1959, **10**, 51. Road Research Laboratory, Harmondsworth, Mddx. Earlier anomolous values of the dynamic shear modulus of concrete beams measured by torsional resonance are explained by a theory predicting discrepancies at high harmonic resonances due to warping of the rectangular section. Experiment is in close agreement with this theory and the corrected modulus is not frequency-dependent. The results agree with those obtained for a beam of circular section which require no such connection. G.M.J.

Section D

POLYMERS, ELASTOMERS AND VISCOELASTIC MATERIALS

250. Viscoelastic structural properties of high-polymer solutions and methods for their determination. P. Rehbinder and L. I. Tschumakova, *Phys. Chem.* (*Lpz.*), 1958, **209**, 1–14. [German]

251. Study of the transition of amorphous and crystalline polymers from the solid into the fluid state on addition of substances of low molecular weight. V. A. Kargin, G. L. Slonimsky and L. Z. Rogovina, *Kolloidnyi Zh.*, 1958, **19**, 142–147. L. Ya. Karpov Physicochemical Institute, Moscow. The transition from solid polymer to fluid solution on addition of solvent resembles the change to a fluid melt on heating, with an intermediate region of high elasticity. The behaviour of polyvinyl chloride is unique in that it remains in a gel form over a wide concentration range. [Russian] A.J.

252. Microgel: an idealized polymer molecule. V. E. Shashoua and R. G. Beaman, *J. Polym. Sci.*, 1958, **33**, 101–117. Pioneering Research Division, E. I. du Pont de Nemours & Co. Inc., Wilmington, Delaware. Pure polymer microgels in solution showed a sudden transition from

low to high viscosity at a critical concentration dependent upon the degree of cross-linking. Equations relating the gel point to the intrinsic viscosity and the latter to the proportion of cross-linking agent are given and discussed. E.H.A.

253. Effect of crystallinity on the viscoelastic properties of polyethylene. KAZUO NAGAMATSU, TETUO TAKEMURA, TATSUYA YOSHITOMI and TATSURO TAKEMOTO, *J. Polym. Sci.*, 1958, **33**, 515–518. Dept. of Applied Science, Faculty of Engineering Kyushu University, Fukuoka, Japan. The failure of the Ferry transform for mechanical data on polyethylene, which is due to changing crystallinity with temperature, may be overcome by introducing an additional shift of the stress-relaxation curves along the *modulus* axis. Good "master curves" may then be obtained providing the strain is not too high, and the crystallinity change with temperature may be deduced from the new shift. E.H.A.

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254. The orientation of polyethylene. R. S. STEIN, *J. Polym. Sci.*, 1959, **34**, 709–720. Dept. of Chemistry, University of Massachusetts, Amherst, Massachusetts. The respective orientations of the crystal and amorphous regions of polyethylene caused by stretching have been studied using the combined techniques of X-ray diffraction, infra-red dichroism and birefringence. That of larger crystalline aggregates was studied by light-scattering and found to be parallel to the crystal orientation. A model consistent with the results of the investigation is proposed. E.H.A.

255. Stress-cracking in polyethylene. P. HITTMAIR, H. F. MARK and R. ULLMAN, *J. Polym. Sci.*, 1958, **33**, 505–507. Polytechnic Institute of Brooklyn, Brooklyn 1, New York, U.S.A. The stress-cracking of various polyethylenes immersed in a fluid which promotes the effect was studied for a number of materials including gamma-irradiated specimens. E.H.A.

256. Polythene household ware, residual moulding strains and service behaviour. G. J. GILBERT, *Plastics, Lond.*, 1958, **23**, 282–286. I.C.I. Plastics Division, Welwyn Garden City, Herts, England. The service behaviour of polythene mouldings is very dependent on moulding conditions. In particular residual strains induced in the article by the injection moulding process can give rise to cracking and delamination when the article is exposed to "active" environments (surface-active agents, polar organic liquids, vegetable and mineral oils). Factors which lead to a high degree of residual strain are discussed, and tests are described which enable the degree of strain in a moulding to be measured. A laminar structure in the moulding can also be detected by a suitable test method. E.B.A.

257. Dynamic mechanical properties of irradiated polyethylene. E. BUTTA and A. CHARLESBY, *J. Polym. Sci.*, 1958, **33**, 119–128. Instituto di Chimica Industriale ed Applicator dell'Universita di Pisa, Pisa, Italy *and* Tube Investments Research Laboratories, Hinxton Hall, England. Dynamic mechanical properties have been measured on a range of irradiated polyethylenes. Minimum values in Young's Modulus with

maximum values in damping factor are found for a critical radiation dose. Three transition regions are exhibited by the sound velocity–temperature curves, and their dependence on radiation dose is discussed. Explanations are advanced in terms of the partial crystallinity of the materials and the changes in molecular structure caused by irradiation.
E.H.A.

258. Laminar flow degradation of polyisobutylene. R. S. PORTER and J. F. JOHNSON, *J. Phys. Chem.*, 1959, **63**, 202. California Research Corporation, Richmond, California, U.S.A. A concentric cylinder viscometer has been used to measure the degradation of 10 per cent solutions of poly*iso*butylene in cetane at temperatures of 25, 40 and 80°C and shear rates up to 3×10^5 sec^{-1} in laminar flow conditions. It is concluded that the degradation occurring under those conditions may be regarded as a " mechanically induced chemical reaction ". D.W.S.

259. The effect of pressure and molecular weight upon the viscosity of polybutenes. L. B. SARGENT, Jr., *Lubric. Engng.*, 1958, **14**, 298–301. Alcoa Research Laboratories, New Kensington, Pa. Tests were carried out on three fractionated samples (A) of narrow molecular weight range, and two commercial samples (B) of wide molecular weight range. The number average molecular weights ranged from 372 to 429. Viscosities were measured in a rolling ball apparatus at pressures up to 20,000 lb/in² and temperature of 80° and 140°F. Results show that samples B behave similarly to samples A of lower average molecular weight. Samples B are less sensitive to pressure and temperature than samples A.
J.F.H.

260. Strain-induced crystallization in polyethylene terephthalate. A. B. THOMPSON, *J. Polym. Sci.*, 1959, **34**, 741–760. I.C.I., Fibre Division, Harrogate, Yorks. The crystallization behaviour of polyethylene terephthalate under stress and at elevated temperatures is explained in terms of a simple viscoelastic theory based on Maxwell's equation. The crystal nucleation density is assumed to depend upon the stress. The theory agrees reasonably well with empirical observations on the " drawing " of the fibre and also points to an internal-stress mechanism for sphenilitic crystallization in which the material is free from external stress.
E.H.A.

261. Cohesive energy density of polystyrene. J. H. S. GREEN, *Nature, Lond.*, 1959, **183**, 818–819. National Chemical Laboratory, Teddington, Middx. The results of viscosity measurements of polystyrene solutions are summarized for use in the determination of its cohesive energy density. Several solvents were used and with some a range of molecular weights was investigated.
W.G.C.

262. The viscosity anomaly at low concentrations with polystyrenes of low molecular weight. D. C. PEPPER and P. P. RUTHERFORD, *J. Polym. Sci.*, 1959, **35**, 299. Trinity College, Dublin, Ireland. The deviations from the linear (η_{sp}/c) versus concentration (c) relationship, found at very low concentrations in polymer solutions, appear at much higher concentrations with low-molecular weight polymers and have been studied.

The effect is possibly due on the one hand to restriction of the effective capillary radius by adsorption of the solute on the walls, and on the other hand to a fall-off of molecular interaction at low concentration. E.H.A.

263. The dynamic mechanical behaviour of polystyrene: atactic and isotactic. R. A. WALL, J. A. SAVER, and A. E. WOODWARD, *J. Polym. Sci.*, 1959, **35**, 285. College of Chemistry and Physics, The Pennsylvania State University, University Park, Pennsylvania, U.S.A. Results on the mechanical loss and dynamic modulus between 80 and 500°K of atactic and isotactic polystyrene are reported. The isotactic polymer has a higher modulus and softening point but the differences in mechanical loss spectrum are not great. E.H.A.

264. Compatibility of nitrocellulose with butadiene-acrylonitrile copolymers. 3. Dependence of the glass transition temperature and flow of nitrocellulose films on their contents of various butadiene-acrylonitrile copolymers. L. E. KALININA, V. I. ALEKSEENKO and S. S. VOYUTSKY, *Kolloidnyi Zh.*, 1958, **19**, 51–58. Central Scientific Research Institute for Leather Substitutes, Moscow. Glass transition and melting temperature and deformations under constant load at various temperatures are reported for a series of mixtures of nitrocellulose with butadiene–acrylonitrile copolymers. [Russian] A.J.

265. Investigation of the structure and properties of carbon chain polymers in dilute solutions. 2. Solutions of vinyl chloride-acrylonitrile copolymer. S. G. ZELIKMAN and N. V. MIKHAILOV, *Kolloidnyi Zh.*, 1958, **19**, 35–40. All-Union Scientific Institute of Artificial Fibres, Mytishchi. The variation in the viscosity of vinyl chloride–acrylonitrile copolymers with temperature and composition has been studied in the range 20–60° and specific and intrinsic viscosities in dimethylformamide have been determined. An attempt is made to interpret the results in terms of molecular structures. [Russian] A.J.

266. Plasticizers for PVC plastisols. D. S. NEWTON and J. A. CRONIN, *Brit. Plast.*, 1958, **31**, 426. British Geon Ltd., Barry, Wales. The type of plasticizer used for making PVC plastisols has a considerable effect on their viscosity (effect of shear rate and ageing) and gelation characteristics, and upon their physical properties after gelation. The differing rheological requirements of paste spreading coating and casting operations are discussed. E.B.A.

267. Investigation of the structure and properties of carbon chain polymers in dilute solutions. 3. Mixtures of polyvinyl chloride and polyacrylonitrile. N. V. MIKHAILOV and S. G. ZELIKMAN, *Kolloidnyi Zh.*, 1958, **19**, 465–477. All-Union Scientific Research Institute for Artificial Fibres, Mytishchi. Osmotic pressure and viscosity at various concentrations and temperatures of dilute solutions of polyacrylonitrile/polyvinyl chloride mixtures have been compared with values for the pure polymers and for copolymers of the same composition as the mixtures. [Russian] A.J.

268. Viscometric characterization of polyvinyl chloride-acetate copolymers. G. CIAMPA and P. L. SBROLLI, *Materie Plastische*, 1957, **23**, 747. The authors report on results of measurements made according to various current viscometric systems on a series of copolymers having the same compositions but differing molecular weights and give tables and graphs to facilitate this comparison. [Italian]

Shortened abstract from *Plastics Tech.*, 1958, **4**, 1059.

269. Effects of blending on the stress-relaxations behaviour of polyvinyl acetate in the rubbery region. K. NINOMIYA, *J. Colloid Sci.*, 1959, **14**, 49–58. Department of Chemistry, University of Wisconsin, Madison, Wisconsin. An assumption made previously [FUJITA and NINOMIYA, *J. Phys. Chem.*, 1957, **61**, 814] that the relaxation spectrum of a blend could be simply represented by linear super-position of the relaxation spectra of the component fractions is checked experimentally. Six blends of six fractions [mol wt. 8×10^4–8×10^5] were examined over temperature range 45°–160°C. Results show that assumption holds only if interaction effects are taken into consideration. R.B.B.

270. Molecular configuration and structure formation in polyacrylate solutions. V. A. KARGIN and N. F. BAKEEV, *Kolloidnyi Zh.*, 1958, **19**, 133–135. Faculty of Chemistry, Moscow State University, U.S.S.R. Globular and fibrillar structures typical of natural polyelectrolytes and proteins have been found in solutions of polyacrylic acid and its salts. The viscosity of a sodium polyacrylate solution passes through a maximum at neutral pH. [Russian] A.J.

271. Poly(methyl methacrylate) in mixed solvents. Part 1. Osmometric and viscometric studies in toluene-ethanol. CHIEN JEN-YUAN, CHING WEN, HO PAO-TSIN and CHENG YUNG-SHIH, *Acta Chim. Sinica*, 1958, **24**, 223–227. [Chinese, English summary]

272. Mechanical behaviour of swollen poly(methyl acrylate) gels. Part 1. Determination of polymer-solvent interaction parameter u by mechanical measurement. Part 2. Stress relaxation in organic solvents. Part 3. Thermoelastic properties of swollen gels. K. OGINO, *Bull. Chem. Soc. Japan*, 1958, **31**, 577–579, 580–583, 584–586.

273. Diaphragm behaviour of plastic disks. A. G. H. DIETZ and F. J. MCGARRY, *Mod. Plast.*, 1958, 135. Plastic Research Laboratory, Massachusetts Institute of Technology, Boston, Mass., U.S.A. The deflection profile of poly(methyl methacrylate) plates under uniform pressure was measured under conditions in which (a) the edges were simply supported, and (b) in which the edges were clamped but allowed to move radially. The deflections followed classical elasticity expressions for large deflections as developed by PRESCOTT (*Applied Elasticity*, Longmans Green, 1924) E.B.A.

274. Shear modulus and internal friction of polymethyl methacrylate and polyethyl methacrylate between 4·2 and 100°K. K. M. SINNOTT, *J. Polym. Sci.*, 1959, **35**, 273. Polychemical Dept., E. I. du Pont de

Nemours & Co., Du Pont Experimental Station, Wilmington, Delaware, U.S.A. Measurements of shear modulus and internal friction between 4·2 and 100°K show a transition at 41°K in polyethyl methacrylate and suggest one below 4·2°K in polymethyl methacrylate. The transition is ascribed to re-orientation of the ester ethyl group. E.H.A.

275. Molecular weight–viscosity relationship of gamma-irradiated octadecyl vinyl ether and octadecyl methacrylate. JEANNE G. FEE, W. S. PORT and L. P. WITNAUER, *J. Polym. Sci.*, 1958, **33**, 95–100. Eastern Regional Research Lab., Eastern Utilization Research & Development Division, U.S. Dept. of Agriculture, Philadelphia 18, Penn., U.S.A. The molecular weight–viscosity relationship was determined for the polymers named prepared by irradiating the monomers with gamma-rays from a cobalt-60 source. E.H.A.

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276. Friction of fibre assemblies. J. D. HUFFINGTON and H. P. STOUT, *Research, Lond.*, 1958, **9**, 450. British Jute Trade Research Association, Dundee, Scotland. The expected variation of friction coefficient with normal load for crossed bundles of fibres is examined mathematically for various situations. Experimental results are given for nylon, jute, terylene and Fibro yarns. E.B.A.

277. Stress–strain–time relationships of non-uniform textile materials. D. KENNY and M. CHAIKIN, *J. Text. Inst.*, 1959, **50**, T18. School of Textile Technology, New South Wales University of Technology, Sydney, N.S.W., Australia. A general relationship has been derived between the extension of, and the load applied to, a specimen of non-uniform cross-sectional area. The behaviour of uniform and non-uniform specimens has been compared analytically for a power law relationship between stress and strain, and is shown to differ significantly when the non-uniform specimen was a truncated cone or when the area varied according to the Gaussian frequency distribution. The extensions under load of typical, non-uniform keratin fibres have been determined by numerical integration to illustrate a general method which may be used for any cross-sectional area distribution and for any stress-strain relationship. The creep behaviour of non-uniform specimens has been similarly treated, with a brief note on the stress-relaxation of non-uniform specimens and on the effect of non-uniformity on such properties as breaking stress, breaking strain and work to extend. It is suggested that the mathematical procedures used can be employed to study other rheological phenomena in non-uniform samples. D.W.S.

278. Tensile properties of textile fibres at very high rates of extension. G. Holden, *J. Text. Inst.*, 1959, **50**, T41. British Rayon Research Association, Wythenshawe, Manchester, 22. Data are presented on nylon, Terylene and cellulose acetate continuous filament yarns at rates of strain from 0·33 per cent per sec to 66,000 per cent per sec, the high rates being achieved by a ballistic method. The breaking stresses of all the materials investigated are shown to be greatest at the high rates, and the work of rupture of medium tenacity nylon appears to decrease to a minimum at 4000 per cent per sec. The work of rupture of high-tenacity nylon is shown to increase with increased rate of strain, and that of the

Terylene and cellulose acetate specimens to remain constant. In an addendum the author presents further results for viscose rayon. A discussion is also appended. D.W.S.

279. Characterization of the high-speed impact behaviour of textile yarns. J. C. SMITH, F. L. MCCRACKIN and M. F. SCHIEFER, *J. Text. Inst.*, 1959, **50**, T55. National Bureau of Standards, Washington, D.C., U.S.A. This paper discussed how the behaviour on impact of textile yarns may be characterized in terms of such parameters as tenacity–strain data, breaking energy density, limiting breaking velocity and critical velocity. Methods are given for obtaining the parameters from tests involving speeds of impact of 50 m/sec or less. At greater speeds of impact, strain–wave phenomena become appreciable, but the behaviour of the yarn may be studied by transverse impact methods. The results of a wave theory for transverse impact are given. The theory is then applied in a method for measuring longitudinal strain-wave velocity, and in two methods for obtaining tenacity–strain curves from high-speed transverse impact tests. A discussion is appended. D.W.S.

280. The dynamic mechanical properties of wool at very low frequencies. F. WARBURTON, *J. Text. Inst.*, 1959, **50**, T1. Wool Industries' Research Association, Headingley, Leeds. The dynamic mechanical properties of wool fibres in simple extension have been measured by oscillatory methods at frequencies from 2×10^{-4} to 1·7 c/s, with three different conditions of temperature and water content. The results are discussed in terms of the usual viscoelasticity theory and it is concluded that the effect of raising the temperature is similar to that of adding a plasticizer to other high polymers, but the effect of water is more complicated. A considerable discussion of the paper by a number of workers in this field is appended. D.W.S.

281. Fibre structure and mechanical properties of untreated modified cottons. R. S. ORR, L. B. DELUCHA, A. W. BURGIS and J. N. GRANT, *Text. Res. J.*, 1959, **29**, 144. Southern Regional Research Labs., New Orleans, Louisiana, U.S.A. A brief review of investigations relating fibre structure to mechanical properties of cotton is given. The relationship of fibril alignment, as measured by the X-ray technique, to the strength and elongation properties of cottons covering a wide range in physical properties is discussed. Alterations of mechanical properties of cotton brought about by degradation in hydrochloric acid, mercerization, decrystallization in ethylamine, resin treatment, and acetylation are related to changes in fibre structure. The effect of stresses imposed during some of the treatments are discussed. D.W.S.

282. Mechanical properties of chemically modified cottons. C. M. CONRAD, *J. Text. Inst.*, 1959, **50**, T133. The breaking strength, yarn knot strength, tearing strength, ultimate elongation, average tensile and flexural stiffness, toughness index, frictional behaviour, creep, elastic recovery, resilience and abrasion resistance have been investigated for some chemically modified cottons. D.W.S.

283. The degree of polymerization and its distribution in cellulose rayons. Part VII. The intrinsic viscosity and degree of polymerization of secondary cellulose acetate fractions. R. J. E. CUMBERBIRCH and W. G. HARLAND, *J. Text. Inst.*, 1958, **49**, T664. British Cotton Industries' Research Association, Shirley Institute, Didsbury, Manchester, 20. The fractionation of two secondary cellulose acetates is described, the degree of polymerization of all the fractions were derived from osmotic measurements in ethyl lactate and of some of the fractions from measurements in acetone, in 80/20 v/v acetone/water mixture, in pyridine at 25°C and 60°C, and in 70/30 methydene chloride/ethanol. The relations between degree of polymerization and intrinsic viscosity measured in acetone and in 80/20 acetone/water have been established for the range 100–1200 polymer units and 0·8–6·8 decilitres per gramme. D.W.S.

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284. On the factors which determine the structural-mechanical properties of viscose solutions. N. N. ZAVYALOVA and N. V. MIKHAILOV, *Kolloidnyi Zh.*, 1958, **20**, 708. Institute of Scientific Research in Fibre Technology, Mytishchi. Viscose solutions 10–12 per cent are studied in a Shvedov concentric cylinder viscometer, apparent viscosities being related to ageing processes. It is suggested that both number and strength of intermolecular linkages increase with age. [Russian. English abstract.] G.W.S.B.

285. Investigations on the structuromechanical properties of ethylcellulose solutions and the effect of oxidation on these properties. T. I. SAMSONOVA and L. V. IVANOVA-CHUMAKOVA, *Kolloidnyi Zh.*, 1958, **19**, 343–352. Institute of Physical Chemistry, Academy of Sciences of U.S.S.R., Moscow. The viscoelastic properties of solutions of ethycellulose of different degress of substitution and of oxidised ethylcellulose have been reported. [Russian] A.J.

286. Effect of velocity gradient and cellulose concentration on viscosities of cellulose solutions. M. HORIO, S. ONOGI, Y. TANIGUCHI, T. KOBOYASHI and H. KURODA, *J. Soc. Text. Cell. Ind. Japan*, 1957, **13**, 830–836. The flow curves of three kinds of cellulose materials such as purified cotton and wood pulps in cupriethylene diamine solution (CED) and cuprammonium solution (CAM) have been measured over a wide range of velocity gradients. The viscosity measurements were carried out by employing a capillary viscometer with a continuously varying pressure head. The cellulose solutions are non-Newtonian unless the concentration is extremely low. For concentrations $< 3/[\eta]$ the wood pulps in CED behave practically as Newtonian liquids and the intrinsic viscosity may be determined from a single point. In the case of higher mol. wt. celluloses, such as cotton, much more dilute solutions must be used in order to apply the single point method. Although the concentrated solutions exhibit marked non-Newtonian behaviour, the apparent viscosities become constant at low velocity gradients. Hence the measurement of intrinsic viscosity by the single point method should be made on a dilute solution at as low a velocity gradient as possible. Even the most dilute solution of a dissolving pulp for viscose in CAM (0·522 g/100 ml) in the present work exhibits non-Newtonian behaviour. [Abstract from *J. Soc. Dy. Col.*, 1958, **74**, No. 9, 674]

287. Viscosity-temperature relationships for dilute solutions of cellulose derivatives. I. Temperature dependence of solution viscosities of ethyl cellulose. W. R. MOORE and A. M. BROWN, *J. Colloid Sci.*, 1959, **14**, 1–12. Physical Chemistry Research Laboratories, Bradford Institute of Technology, Bradford. Viscosities of dilute solutions of six fractions of ethyl cellulose, molecular weight range 40,000–140,000 in six solvents have been determined at temperatures between 25° and 60°C. Results are represented by the expression $\eta = A \exp [Q/RT]$. The apparent activation energy of viscous flow, Q, is linearly related to the concentration and molecular weight. R.B.B.

288. Viscosity of cellulose fibre and the effect of non-cellulosic constituents on the viscosity. H. CHATTERJEE, *Sci. Culture*, 1958, **23**, 630–632.

289. The strain dependence of stress relaxation in cellulose monofilaments ELIO PASSAGLIA and H. P. KOPPEHELE, *J. Polym. Sci.*, 1958, **33**, 281–289. Research & Development Division, American Viscose Corporation, Marcus Hook, Penna., U.S.A. Stress-relaxation measurements were made on cellulose filaments at strains between 0·5 and 5 per cent at two temperatures. The results may be superposed by translation along the time axis of the log (modulus)–long (time) curves. This may result from a common strain-dependence of all the relaxation time. Relaxation distribution functions are obtained which are broader for isotropic filaments than for oriented ones. E.H.A.

290. The relation between intrinsic viscosity and degree of polymerization for cellulose and its principal derivatives. R. J. E. CUMBERBIRCH and W. G. HARLAND, *J. Text. Inst.*, 1958, **49**, T679. The British Cotton Industries Research Association, Shirley Institute, Didsbury, Manchester 20. The relation between intrinsic viscosity and degree of polymerization has been established for cellulose in cuprammonium, and cellulose triacetate in methylene chloride/ethanol mixture. The relation for cellulose was derived by two independent routes and good agreement was obtained. Tables are given in an appendix whereby degrees of polymerization can be determined directly from cuprammonium fluidity measurements made at cellulose concentration of 2 g/100 ml and 0·5 g/100 ml. D.W.S.

291. Mechanical properties of cellulose fibres. Z. L. SULEIMANOVA and V. A. KARGIN, *Zh. Fiz. Khim.*, 1958, **32**, 811–818. [Russian. English summary.]

292. Adhesion of high polymers. 3. Effects of the size, shape and polarity of high polymer molecules on their adhesion to cellophane. S. S. VOYUTSKY, A. I. SHAPOVALOVA and A. P. PISARENKO, *Kolloidnyi Zh.*, 1958, **19**, 274–280. Central Scientific Research Institute for the Leather Substitutes Industry, Moscow. Adhesion of high polymers to Cellophane increases with decreasing molecular weight and decreases with increasing no. of short side chains in the polymer and increasing content of polar groups. For maximum bond strength, the cohesive properties of the polymer must be taken into account. A.J.

293. The effect of strain on the electrical resistance of keratin. J. E. ALGIE, *Text. Res. J.*, 1959, **29**, 1. Wool Textile Research Labs., C.S.I.R.O., 338, Blaxland Road, Ryde, N.S.W., Australia. The change of resistance with time after the application of various strains has been examined at 90%r.h. and 20°C for keratin fibres. There is an initial instantaneous rise of resistance much greater than that due to a dimensional change, which is related to the strain, followed by a decrease in the resistance caused by the uptake of water vapour from the surrounding atmosphere. A further stage was observed during which the resistance rose as excess water vapour left the fibre. Author

294. Mastication of rubber. VIII. Preparation of block polymers by mechanical shear of polymer–monomer systems. D. J. ANGIER, R. J. CERESA and W. F. WATSON, *J. Polym. Sci.*, 1959, **34**, 699–708. British Rubber Producers' Research Association, Welwyn Garden City, Herts. The polymerization reaction which occurs when a monomer is masticated with another polymer suggests a mechanism of mechanical rupture of the polymer to free radicals which then initiate polymerization. Fractional precipitation methods are used to separate block polymers of polymethylmethacrylate and polystyrene from the mastication products of both initial polymer–monomer mixtures. The block polymers do not contain many segments of each polymer. E.H.A.

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295. Wandering of Crosslinks in rubber at high temperatures. M. J. VOORN and J. J. HERMANS, *J. Polym. Sci.*, 1959, **35**, 113–118. Laboratory for Inorganic and Physical Chemistry, The University, Leiden, The Netherlands. It is shown that the relationship between equilibrium swelling or high-temperature stress-relaxation and crosslink density in natural rubber vulcanizates is not unique but depends upon the conditions under which the network is formed. Care must therefore be exercised in calculating crosslink density from swelling or stress data. E.H.A.

296. Shape factors and functions in rubber engineering. A. R. PAYNE, *Engineer, Lond.*, 1959, **207**, 328–333, 368–370. This article describes experiments to determine the form of the stress–strain relationships in compression for flat rubber pads of circular, rectangular, and square cross-sections as well as pads of circular cross-section with a central hole, under static and dynamic conditions and under bonded or lubricated conditions. The effect of fillers in the rubber composition on these relationships is discussed. Next, the static and dynamic stress–strain relationships for a rubber mounting deformed in shear is considered, and the experimental results shown to be in conformity with the theory derived from classical elasticity theory. The shape function and shape factor of a shear mounting are discussed. From a combination of the shape functions in sheer and in compressions, a theoretical expression for the stress-strain relationship for a combined shear and compression mounting is derived which agrees well with experiment. Author

297. The effect of swelling on the strength of vulcanizates. B. A. DOGADKIN, D. L. FEDYUKIN and V. E. GULI *Kolloidnyi Zh.*, 1958, **19**, 287–292. M. V. Lomonosov Institute of Fine Chemical Technology,

Moscow. Tensile strength and relative elongation of rubber vulcanizates sometimes pass through maxima at low degrees of swelling. A molecular interpretation of this effect is given. A.J.

298. Investigation of adhesion effects in bonding rubber to metal by Leukonat adhesive. A. M. MEDVEDEVA, B. V. DERYAGIN and S. K. ZHEREBKHOV, *Kolloidnyi Zh.*, 1958, **19**, 412–420. Institute of Physical Chemistry, Academy of Sciences of U.S.S.R., Moscow. Bonding of metal to rubber by isocyanate adhesives is affected greatly by the nature of the filler in the rubber. Sand-blasting of the metal surface increases the true contact area by 1·5–2, but the bond strength increased by 20–100-fold. A.J.

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299. Tensile strength of filled GR-S vulcanizates. F. BUECHE, *J. Polym. Sci.*, 1958, **33**, 259–271. Physics Dept., University of Wyoming, Laramie, Wyoming. A molecular theory previously advanced to explain the strength of rubbers is extended to filled GR-S materials. Tensile strength was measured as a function of filler concentration, temperature and degree of crosslinking. The results are held to confirm the theory. E.H.A.

300. The rupture process in carbon loaded rubbers. An electron-microscopic investigation. E. H. ANDREWS and A. WALSH, *J. Polym. Sci.*, 1958, **33**, 39–52. The British Rubber Producers Research Assn., Welwyn Garden City, Herts, England, and Dept. of Applied Physics, Northampton College of Advanced Technology, London, England. Replica electron microscopy of rupture surfaces in carbon-filled rubbers provides information about the process of rupture in these materials. Different types of rupture, of filler and of rubber are studied. An estimate is made of the adhesion of filler to rubber in the rupture surface, and is found to correlate with the tearing energy. Simple theories are suggested to explain the results. E.H.A.

301. Synthetic polymers. Part 4. Variation of condensation and mechanical properties of phenoplast-cast resins as a function of their composition. R. BALLO and I. GECZY, *Periodic Polytech.*, 1958, **2**, 99–111.

302. Effects of composition, curing conditions, and fillers on dynamic mechanical properties and on structure of phenol-formaldehyde resins. M. BACCAREDDA and E. BUTTA, *Chim. e Industri*, 1958, **40**, 732–735.

303. The hardening mechanism of thermosetting plastics (moulding powders). I. F. KANAVETS, L. G. BATALOVA and A. G. ROMASHOVA, *Kolloidnyi Zh.*, 1958, **19**, 204–218. Scientific Research and Planning Inst. of the Plastics Industry, Moscow. The chemical and physical processes occurring simultaneously in the moulding of a thermosetting resin are considered and the requirements for an ideal moulding powder evaluated. A.J.

304. Reinforced plastics. C. GURNEY, *Nature, Lond.*, 1959, **183**, 24–25. This is a brief report of a Conference, organised by the British Plastics Federation at Brighton, on the production, properties and uses of plastics reinforced by glass in the form of fibres or flakes. W.G.C.

305. Assessment of cure in mouldings. A. A. TOMKINS, *Trans. Plast. Inst. Lond.*, 1958, **26**, 389. Joseph Lucas Ltd., Birmingham. The problem of measuring degree of cure in thermosetting mouldings is discussed with particular reference to hot-needle penetrometer tests. E.B.A.

306. Heat ageing characteristics of bis-phenol-epoxy resins. P. NOWAK and E. STEINBACHER, *Kunststoffe*, 1958, **48**, 558. Chemischen Zentrallaboratorium der A.E.G. Kassel. The ageing characteristics of a particular bis-phenol-epoxy resin at different hardener concentrations were investigated by measuring torsion oscillation and shrinkage. Their significance in relation to ageing properties is discussed. [German]

307. Properties of foams and laminates under shock loading. R. H. SUFRIK and M. SILBERBENG, *S.P.E.J.*, 1959, **15**, 43. The results of tensile and compression modulus and tensile strength measurements of foams and laminates with a range of densities are presented. The Instron Tensile Tester and the Plastechon High Speed Tester were used, the latter measuring the dynamic properties. The two methods gave significantly different results, particularly with higher density materials.

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308. Investigations of the physical chemistry of agar. 1. Method for the determination of the intrinsic viscosity of agar. S. A. GLIKMAN and I. G. SHUBTSOVA, *Kolloidnyi Zh.*, 1958, **19**, 172–177. Dilute solution viscosities of agar solutions containing varying amounts of electrolyte are reported. [Russian] A.J.

309. Statistical-graphical survey of series of linear and cyclic dimethyl siloxanes. H. I. WATERMAN, W. E. R. VAN HERWIJNEN and H. W. DEN HARTOG, *J. Appl. Chem.*, 1958, **8**, 625. Institute of Chemical Engineering, Technaldgical University, Delft. It is shown that by plotting v_{20}/v_{70} *vs.* v_{20} (v=kinematic viscosity) it is possible to determine the average number of silicon atoms per molecule in a mixture of linear and cyclic siloxanes, and the average ratio of silicon atoms in linear structure to those in cyclic structure and to predict physical constants of siloxanes when two of them are known. Author's abstract, abridged

310. Studies of the physical chemistry of agar. 2. Theory and practice of agar fractionation. S. A. GLIKMAN and I. G. SHUBTSOVA, *Kolloidnyi Zh.*, 1958, **19**, 281–286. N.G. Chemyshevsky State University, Savatov. Agar is fractionated by a differential solubility method and the fractions characterized by viscosity measurements. [Russian] A.J.

Section E

PASTES AND SUSPENSIONS

311. Particle motions in sheared suspensions. A. P. ARLOV, O. L. FORGACS and S. G. MASON, *Svensk Pappers Tidning*, 1958, **3**, 61–67. Physical Chemistry Division, Pulp and Paper Research Institute of Canada, Montreal. The rotations and spins executed by woodpulp fibres suspended in a liquid subjected to laminar shear are described. It is shown that the type of rotation depends upon whether the fibres are rigid or flexible. When rigid, the fibres spin and rotate in spherical elliptical orbits in the same general manner as smooth rigid rods for which

the theory is well developed. When the fibres are flexible, the rotations are much more complicated. It has been found possible, however, to make a simple classification of types of rotational orbits, which it is suggested, may serve as a quantitative method of measuring the spectrum of fibre flexibilities. Unlike rigid fibres, isolated flexible fibres show a pronounced tendency to assume one of two preferred rotational orbit constants, one corresponding to pure spin without rotation and the other to pure rotation without spin. On the other hand, in dilute suspensions the steady state distribution of orbit constants of fibres is similar to that in suspensions of rigid rods of comparable axis ratio where, it has been shown, the distribution is determined by interaction effects. Periods of rotation T of flexible fibres are substantially lower than for rigid rods of corresponding axis ratio. The product TG of rigid rods remains constant over a range of velocity gradients G whereas with flexible fibres it increases appreciably with increasing G, an effect which has been shown to be associated with the accompanying increase in the amount of fibre deformation during rotation. Author

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312. Influence of non-Newtonian viscosity on the molecular weight-intrinsic viscosity relationship of high polymer solutions. K. KAWAHARA, M. UEDA, Y. OKA and T. KUROIAW, *J. Chem. Soc. Japan*, 1958, **79**, 843–848. [Japanese]

313. Particle motions in sheared suspensions. VIII. Singlets and doublets of fluid spheres. W. BARTOK and S. G. MASON, *J. Colloid Sci.*, 1959, **14**, 13–26, 1. Department of Chemistry, McGill University, Montreal. The spin of single liquid spheres of carbon tetrachloride and cyclohexanol phthalate suspended in corn syrup was measured over a range of laminar shear rates and was found to be practically identical with the value for rigid spheres. No fluid circulation inside the drops was evident until the gradient increased sufficiently to deform the drops. The variation of drop deformation with initial diameter and velocity gradient agreed with Taylor's theory. Experiments are also reported in which glycerine was used as the suspension medium. R.B.B.

314. Interaction between two equal-sized equal-setting spheres moving through a viscous liquid. G. F. EVESON and G. W. HALL, *Brit. J. Appl. Phys.*, 1958, **10**, 43. Dept. of Mining, Birmingham University. An experimental investigation of the interaction between two equal spheres settling through a viscous liquid at various distances apart and with the line of their centres at various angles to the horizontal. The results are represented by empirical equations and compared with some theoretical predictions. G.M.J.

315. Flocculation, subsidence and filtration of phosphate shines. VI. A quantitative theory of filtration of flocculated suspensions. R. H. SMELLIE and V. K. LA MER, *J. Colloid Sci.*, 1958, **13**, 589–599. Dept. of Chemistry, Trinity College, Hertford, Connecticut. A qualitative theory of filtration of suspensions flocculated with polymeric flocculants is developed. The theory, based upon a simple picture of the adsorption of the flocculant combined with considerations of floc geometry and the Kogeny–Carman permeability equation, explains the variations of filtration rate with flocculant concentration observed experimentally. [English] Author

316. Thixotropic and structuromechanical properties of askangel suspensions in relation to the composition of the exchange complex. E. I. KOBAKHIDZE, M. E. SHISHNIASHVILI and N. N. SERB-SERBINA, *Kolloidnyi Zh.*, 1958, **19**, 299–306. Institute of Physical Chemistry, Acad. Sci., U.S.S.R., Moscow. The effect of cation exchange on the mechanical properties of askangel suspensions is described. [Russian] A.J.

317. Action of the basic salt aluminium oxychloride on the structuromechanical properties of askangel suspensions. E. D. UZNADZE and M. E. SHISHNIASHVILI, *Kolloidnyi Zh.*, 1958, **19**, 368–375. Academy of Sciences of Georgian SSR, Tbilisi. Addition of less than 0·1 per cent of aluminium oxychloride greatly increases the strength of the thixotropic structure formed by askangel suspensions. A.J.

318. Effect of electrolytes on the structuromechanical properties of bentonite suspensions. I. A. USKOV, *Kolloidnyi Zh.*, 1958, **19**, 511–514. T. G. Shevchenko State University, Kiev. Considerable increases in the strength, elasticity and viscosity of askangel suspensions are produced by addition of electrolytes. [Russian] A.J.

319. Possible differences in the composition and viscosity ratio of a two-sided film and a surface layer of a soap solution. A. A. TRAPEZNIKOV, *Kolloidnyi Zh.*, 1958, **19**, 252–255. Institute of Physical Chemistry, Academy of Science of U.S.S.R., Moscow. Surface viscosity measurements indicate that a two-sided soap film is appreciably different in properties from the film formed at the surface of the bulk soap solution. A.J.

320. Thermodynamic barrier to micelle formation and breakdown. I. Cetyl trimethyl ammonium salts. T. NASH, *J. Colloid Sci.*, 1959, **14**, 59–73. Central Public Health Laboratory, Colindale Avenue, London, N.W.9. Slow rates of equilibrium in the micellar solution of dilute aqueous cetyl trimethyl ammonium bromide containing a little sodium bromide acid arise from the viscoelastic nature of the solution. Addition of naphthol to the solution enhances the viscoelastic properties. The viscoelastic properties of the solution are used to study micelle formation and structure. R.B.B.

321. Relation between viscosity and critical micelle concentration of detergent solutions. III. Relations between micellar mol. wt., viscosity and critical micelle concentration of detergent solutions. K. TYUZYO, *Bull. Chem. Soc., Japan*, 1958, **31**, 117–122. Association numbers n and critical micelle concentration C_c for a number of anionic and cationic detergents are related by the expression :—

$$n = 17{\cdot}0 \left(\frac{1}{C_c}\right)^{0{\cdot}29}$$

independently of added electrolytes. Micellar molecular weight M_m and intrinsic viscosity $[\eta_1]$ and $[\eta_2]$ of both ionic and non-ionic detergents are related by the expressions—

$$\log M_m = 0{\cdot}41\,(\log n\,[\eta_1])^2 - 0{\cdot}39\,(\log n\,[\eta_1]) + 3{\cdot}47$$
$$= 0{\cdot}45\,(\log n\,[\eta_2])^2 - 0{\cdot}91\,(\log n\,[\eta_2]) + 4{\cdot}04$$

For definitions and explanations of $[\eta_1]$ and $[\eta_2]$ see SATA and TYUZYU, *ibid*, 1953, **26**, 177. [Abstract from *J. Soc. Dy. Col.*, 1958, **74**, 608]

322. Studies on aluminium hydroxide hydrosols. 4. Thixotropic gelation of the sol in methyl alcohol-dioxane mixtures. P. V. RUFIMSKII, *Kolloidnyi Zh.*, 1958, **20**, 739. Ulyanov-Lenin State University of Kazan, Dept. of Chemistry. A qualitative picture has been obtained of the gelation of aluminium hydroxide sols in the presence of dioxane and in mixtures of dioxane-methyl alcohol. Besides the typical thixotropic gels, still another, clotty gel is formed in both cases. The region of thixotropic gelation in the case of dioxane is wider and shifted in the direction of maximum concentration of the latter. This indirectly confirms the fact that methyl alcohol evidently does not influence the thixotropic gelation of aluminium oxide sols. [Russian. English abstract] Author

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323. Critical concentration effects in dilute solution viscosities of polymers. S. GUNDIAH snd S. L. KAPUR, *J. Sci. Industr. Res.*, 1958, **17B**, 330–331. National Chemical Laboratory, Poona 8, India. In this note reference is made to published work on the anomalous viscosity behaviour of polymer solutions at high dilutions. The results of experiments on two fractions of polystyrene are reported, and these, it is suggested, show that the anomalous viscosity behaviour is a critical concentration effect. This effect results from the configurational changes of polymer molecules with increased dilution of their solutions. Earlier work of these authors is cited (cf. *Rheology Abstracts*, 1958, **1**, 14, No. 416) as support for this view. W.G.C.

324. Investigation of structurized suspensions. E. F. KURGAEV, *Kolloidnyi Zh.*, 1958, **19**, 72–77. All-Union Scientific Research Institute for Railway Transport, Moscow. Density, strength in normal uniaxial compression, amount of immobilized water and cohesion forces causing floc aggregation are determined for some flocculent suspensions formed in water softening processes. A.J.

325. Gelatinized emulsions. 13. o/w type emulsions of maximum concentration with a thixotropic dispersion medium. L. YA. KREMNEV, *Kolloidnyi Zh.*, 1958, **19**, 68–71. Lensoviet Technological Institute, Leningrad. Emulsion of oil in a thixotropic sodium oleate solution have a very high degree of dispersion and are homogeneous in droplet size. The stability is determined chiefly by the structural and mechanical properties of the protective adsorbed solvate layers. [Russian] A.J.

326. Thixotropic structure formation and elasticoplastic-oviscous properties of askangel suspensions. E. I. KOBAKHIDZE and M. E. SHISHNIASHVILI, *Kolloidnyi Zh.*, 1958, **19**, 59–67. Academy of Sciences of Georgian SSR. and Colloid Chemistry Laboratory, Tbilisi. The effect of pH on the thixotropic properties of a series of askangel bentonite pastes has been studied. A.J.

327. The velocity of sound in emulsions. P. A. ALLINSON, *J. Colloid Sci.*, 1958, **13**, 513–521. Physics Department, King's College, University of Durham, Newcastle upon Tyne. The velocity of sound in emulsions of benzene in water was measured, the viscosity of the continuous phase being varied by the addition of glycerine to the water, and the density of the disperse phase varied by the addition of carbon tetrachloride to the

benzene. The results so obtained were compared with two theories, one assuming the emulsions to be homogeneous mixtures of the two components of a mean density and compressibility, the second derived from carried erations of the scattering of sound energy from the suspended particles. The experimental results lay close to the values derived from the first assumption. Author

328. Industrial unit for production of emulsions by means of a liquid whistle (jet). S. I. SINKOVA and S. A. PUSYREV, *Kolloidnyi Zh.*, 1958, **19**, 38–389. Central Scientific Research Institute for Cellulose and Paper Industry, Leningrad. A high-speed liquid jet is caused to infringe on the edge of a plate. By suitable adjustment of the geometry of the system, the plate is thereby made to resonate at ultrasonic frequencies. [Russian] A.J.

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329. Changes in the structure degree of dispersion, and yield value of peats as a result of complete freezing. M. P. VOLAROVICH, K. F. GUSEV, S. N. MARKOV and V. P. TROPIN, *Kolloidnyi Zh.*, 1958, **19**, 401–405. Moscow Peat Institute. The yield value of frozen peat, after thawing, is considerably lower than that of the original peat. The physical changes which occur are investigated. A.J.

330. Improvement of certain Indian refractory clays by pH control. H. P. S. MURTHY and J. R. K. MURTHY, *J. Sci. Industr. Res.*, 1958, **17A**, 321–325. National Metallurgical Laboratory, Jamshedpur, India. Thirteen Indian refractory clays have been studied with a view to improving their workability and dry strengths. The variation in the pH values of these clays with increasing additions of Na_2CO_3 (up to 1 per cent) and the consequent effect on dry strength of the clays have been determined, using the method for the modulus of rupture specified by the American Ceramic Society. W.G.C.

331. On the processes of structure-formation in compacted foundation-soils. T. YU. LYUBIMOVA, *Kolloidnyi Zh.*, 1958, **20**, 719. All-Union Roads Scientific Institute. Relationships are discussed between mechanical strength and moisture content. These are markedly affected by addition of surface-active molecules (sodium oleate), which intensify the increase in mechanical strength by interfering with syneretic processes. [Russian. English abstract] G.W.S.B.

332. Study of the structure of clay suspensions. MADELEINE MARTIN, *Rev. Inst. franç. Pétrole*, 1958, **13**, 1102–15. Institute Français du Pétrole, Paris. A critical review of already published data on aqueous suspensions of bentonite. Although a great deal is known about the structure of the individual hydrated clay leaflets in the suspension, the relationships between grosser structures and the macroscopic (including rheological) properties of the suspension are still unknown. [French] J.F.H.

333. On the viscosity of suspensions of clay with their structure destroyed to a controlled degree, and on the influence of sodium hydroxide on them. L. A. ABDURAGIMOVA and N. G. ALEKPEROVA, *Kolloidnyi Zh.*, 1958, **20**,

681. Institute of Chemistry, Academy of Sciences of Azerbaidyan S.S.R. Clay suspensions sheared at high stresses in capillaries gives flow-curves which include a Newtonian "Laminarast". Bentonites are shown to absorb alkali more than do kaolins. Small additions of alkali increase Laminarast viscosity, whereas large additions decrease it. [Russian. English abstract] G.W.S.B.

334. Effect of an active filler and a solvent on the structural and mechanical properties of bitumens. S. YA SHALYT, N. V. MIKHAILOV and P. A. REBINDER. *Kolloidnyi Zh.*, 1958, **19**, 244–251. Scientific Research Institute for Building, Ministry of Construction, U.S.S.R. Moscow. By blending into bitumen an active filler (slaked lime) and a plasticizer (green oil solvent) it is possible to obtain both a high viscosity and a lower temperature coefficient of viscosity. A.J.

335. Some factors influencing the behaviour of bitumen road surfaces. G. M. DORMON and A. W. JARMAN, *J. Appl. Chem.*, 1958, **8**, 832. Shell Petroleum Co. Ltd., London. The concept of the stiffness of bitumen (ratio of tensile stress to tensile strain) and methods for its determination are described with special reference to the behaviour of road surfacings under different conditions. The mechanism of the failure of road surfacings (cracking, deformation, under load, and fretting) and factors which may interfere with the expected functions of the mixture (durability and adhesion) are studied in detail. Author

336. A new method for calculating the flow of lubricating greases. D. W. CRIDDLE, *N.L.G.I. Spokesman*, 1958, **22**, 381–385. California Research Corp. A new method is given for calculating the flow of greases. The method is partly empirical in approach. Possible advantages and limitations of the method are discussed.

337. The structure of gels. 9. Effect of the nature of the plasticizer on the physicomechanical properties of divinyl-styrene rubber. M. P. ZVEREV and P. I. ZUBOV, *Kolloidnyi Zh.*, 1958, **19**, 201–203. L. Ya. Karpov Physicochemical Institute. The glass transition and melting temperature, tensile strength and extensibility of a divinyl–styrene rubber containing varying amounts of different plasticizers are reported. [Russian] A.J.

338. Critical concentration effects in dilute solution viscosities of polymers. S. GUNDIAH and S. L. KAPUR, *J. Sci. Ind. Res., India*, 1958, **17B**, 330–331.

339. Thixotropic gel formation. T. WATANABE and Y. TAKASAKI, *Naturwiss.*, 1958, **45**, 334–335.

340. The maximum ultimate deformation and related sheer strength of a structure as influenced by aluminium naphthenate oleogel concentration. V. A. FEDOBOVA and A. A. TRAPEZENIKOV, *Dokl. Akad. Nauk. SSSR*, 1958, **120**, 841–844. [Russian]

341. Investigation of the mechanical properties of plastic disperse systems in conditions of uniaxial extension and compression. E. P. MOSIKHIN and G. V. VINOGRADOV, *Kolloidnyi Zh.*, 1958, **19**, 311–318. (I. V. Stalin

Military Academy of Armoured and Tank Forces). Specimens of homogenized calcium solidol greases fail plastically in tension (Young's Modulus 3000 g/cm). The elastic region comprises a few tenths of one per cent. The tensile strength/shearing strength ratio is 2. A.J.

342. Purification and viscosity experiments on gum arabic. L. K. H. VAN BEEK, *J. Polym. Sci.*, 1958, **33**, 463–469. Dept. of Chemistry, University of Khartoum, Sudan. The effect of ionic impurities on the viscosity of gum arabic is studied. The impurities, which are present naturally, may be removed by use of a cation exchange resin. The decrease in limiting viscosity number caused by these impurities can be explained in terms of electrovalent or covalent crosslinking. E.H.A.

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343. Effect of surface-active substances on the specific viscosity of gelatin solutions. S. M. LEVI, *Kolloidnyi Zh.*, 1958, **19**, 78–81, Scientific Research Institute for Cinephotography, Moscow. The increased viscosity of gelatin solutions on adding wetting agents is attributed to adsorption of the latter leading to a change in the shape of the gelatin molecule. [Russian] A.J.

344. High viscosity of cell wall suspensions prepared from tomato juice. R. T. WHITTENBERGER and G. C. NUTTING, *Food Tech.*, 1958, **12**, 420–424. Eastern Regional Research Laboratory, Philadelphia 18, Pennsylvania. Viscosity of tomato juice was doubled and even tripled by removing the soluble components from the juice. For example, viscosity was increased from 230 apparent centipoises (cp.) to 700 cp. by washing the juice on a fine sieve. The washed product resembled a puree in consistency, although its solids content was only 0·7 per cent. Viscosity remained high following the addition of soluble non-ionic substances such as sugars, but was reduced greatly by the presence of electrolytes. Even the small amount of electrolyte occurring naturally in fresh tomatoes was sufficient to hold viscosity at a relatively low value. Microscopic observations and chemical tests showed that high viscosity was associated closely with the cell wall fraction of the juice. Pure cellulose walls at a concentration of only 0·2 per cent. gave a suspension as thick as the original whole juice containing 6·3 per cent. total solids. Author

345. Viscous behaviour of polymerized vegetable oils. R. P. A. SIMS, *J. Amer. Oil Chem. Soc.*, 1958, **35**, 257–261. Canada Department of Agriculture, Ottawa, Ontario. Extraction of thermally polymerized linseed oil with acetone at various temperatures yielded fractions at higher temperatures that had high molecular weights and gave intrinsic viscosity and critical miscibility plots resembling those of high polymers. Unheated oil was not an indifferent solvent for polymerized oil as judged by the temperature coefficient of intrinsic viscosity. Molecular weight information obtained with non-randomized samples suggested a linear relation between log viscosity and $(M_n)^{\frac{1}{2}}$ for molecular weights up to 2500. With weight average molecular weights a linear relation between log viscosity and $(\overline{M_w})^{\frac{1}{2}}$ obtains at molecular weights greater than 40,000. Randomization of the samples decreased their bulk viscosity while increasing polymer content. Author

346. The effect of salts upon starch granule rupture. S. S. WINTER and A. A. LOISELLE, *J. Colloid Sci.*, 1958, **13**, 576–583. Department of Chemistry, Northeastern University, Boston, 15, Massachusetts. Viscosity measurements show that salts do not affect the rate of starch granule rupture. This indicates that only the solvent plays a major rate in the swelting process. The salts affect the conformations of the hydrated starch molecules in the same manner in which electrolytes affect other polyelectrolytes. Author

347. The rheology of aqueous solutions of amylose and amylopectin with reference to molecular configuration and intermolecular association. B. T. STOREY and E. W. MERIILL, *J. Polym. Sci.*, 1958, **33**, 361–375. Dept. of Chemistry, Harvard University, Cambridge Mass., and Dept. of Chemical Engineering, Massachusetts, Institute of Technology, Cambridge, Mass., U.S.A. Models based on the concept of a single-point network association link are developed to describe the behaviour of aqueous solutions of amylose and amylopectin, and expressions relating shear stress, shear rate and time of shear derived. Experimental data is in agreement with these expressions and thus supports the proposed models. E.H.A.

348. Distribution of relaxation times in a symmetrically stressed renneted, milk gel. G. W. SCOTT BLAIR and J. BURNETT, *Brit. J. Appl. Phys.*, 1959 **10**, 97. National Institute for Dairying Research, University of Reading, Berkshire, England. Experiments on certain curds indicate a log-normal distribution of relaxation times if strain-stiffening is minimized by altering the direction of stress and if the time zero is suitably fixed. The disparity between the immediate elastic displacement under load and the immediate recovery is now explained by static fatigue. G.M.J.

349. Physical changes in milk caused by the action of rennet. IV. Effects of varying rennet concentration and temperature. G. W. SCOTT BLAIR and J. BURNETT, *J. Dairy Res.*, 1959, **26**, 58. Nat. Inst. Res. Dairying, Reading. Overall rigidity modulus is linearly related to log time of setting. The slopes of these curves vary as the cube root of rennet concentration and their intercepts, inversely as the concentration. Some rheological parameters increase progressively with temperature (21–41°C), others show maxima or minima between 29° and 35°C. Temperature dependence of creep and relaxation is also discussed. G.W.S.B.

350. An equation for the flow of blood, plasma and serum through glass capillaries. G. W. SCOTT BLAIR, *Nature, Lond.*, 1959, **183**, 613–614. National Institute for Research in Dairying, University of Reading. Flow data for pigs', cows' and human blood are shown to fit the equation $\tau^{\frac{1}{2}}=k_0+k_1D^{\frac{1}{2}}$ derived by N. CASSON, where τ is the shear stress and D the shear rate. For wide capillaries ($<0{\cdot}15$ mm diameter) k_0 and k_1 are little altered by changes in diameter, but in narrower tubes the changes become much more marked. This may be related to the " sigma phenomenon ". W.G.C.

351. On the creep, recovery, relaxation and "elastic memory" of some renneted milk gels. G. W. SCOTT BLAIR and J. BURNETT, *Brit. J. Appl. Phys.*, 1959, **10**, 15. National Institute for Research in dairying, University of Reading, Berkshire, England. Small pressures are applied to one end of a column of curd in a U-tube and the displacements at the other end measured. The curd behaves approximately as a Burgens body except that the strain for creep is greater than that for recovery and there is an elastic memory on stressing in alternate directions. Creep and relaxation curves follow the superposition principle. Hysteresis curves show marked stiffening followed by a softening if the direction of loading is reversed. Analytical and integrative approaches to the problem are are discussed. G.M.J.

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352. Foam density as a measure of viscosity. (Incomplete equilibrium in dilute solutions of a cationic soap by the foam density method). T. NASH, *J. Appl. Chem.*, 1958, **8**, 440, Air Hygiene Laboratory, Central Public Health Laboratory, London, N.W.9. In a foam each bubble acts as a viscometeric system so that the density after a standard drainage time is a measure of the "viscosity" of the solution. This technique is used to investigate different solution states in aqueous cetyltrimethylammonium bromide. It can be used to measure the critical micelle concentration. E.B.A.

353. The thixotropic properties of certain printing inks. A. A. TRAPEZKNIKOV and T. G. SHALOPALKINA, *Kolloidnyi Zh.*, 1958, **19**, 232–243. Institute of Physical Chemistry, Academy of Sciences USSR, Moscow. The mechanical properties (strength and viscosity) of two newspaper inks are determined in a concentric-cylinder elastoviscometer. A.J.

354. Rheology of paints and related colloidal systems. Part I. L. DINTENFASS, *Paint J. Aust. N.Z.*, 1958, **3**, 18–21. Taubmans Industries Ltd., St. Peters, N.S.W. Australia. A review of macro-rheological classifications and a description of the various coefficients of viscosity ; tensile strength of solids and liquids is mentioned. 20 references. L.D.

355. Rheology of paints and related colloidal systems. Part II. L. DINTENFASS, *Paint J. Aust. N.Z.*, 1959, **3**, 8–20. Taubmans Industries Ltd., St. Peters, N.S.W., Australia. A semi-review. An attempt is made to form an integrated picture of micro-rheology of pigment suspensions, polymer solutions polymer films, and paint films. Pigment flocculation and polymer aggregation are stressed. Polymer orientation, photoelastic phenomena, interface adsorption phenomena, fatigue of polymeric matrix, effects of cyclic stresses, etc., are mentioned. 101 references. L.D.

Section F

LIQUIDS

356. Viscosities of liquid mixtures. T. M. REED III, and T. E. TAYLOR, *J. Phys. Chem.*, 1959, **63**, 58. Dept. of Chem. Engineering, University of Florida, Gainesville, Florida, U.S.A. The viscosities of ten binary liquid systems have been determined as a function of composition and of

temperature in the range 25–45°C. The thermodynamics of these systems range from the ideal solution to partially miscible liquids. The free energy of mixing alone is insufficient thermodynamic information in attempting to correlate the thermodynamic behaviour with the viscosity behaviour. The volume change on mixing and the entropy of mixing are related to separate viscosity effects. Based upon the absolute reaction rate of theory of Eyring these systems have been divided into three classes which differ in the dependence of temperature coefficient of viscosity on temperature. It is found that as the temperature is decreased to approach the two liquid phase region of a mixture, the viscosity as a function of composition displays an abnormally high value. This effect is found at 22° above the critical unmixing temperature for the system composed of iso-octane and perfluoroheptane. This analysis shows that the enthalpy of activation for all solutions may be considered as essentially independent of temperature even though the temperature coefficient of viscosity varies with temperature. Author

357. The accurate measurement of the viscosity of liquids. *J. Inst. Petrol.*, 1958, **44**, 394–400. A symposium, organized jointly by the Institute and the British Society of Rheology, entitled "The accurate measurement of the viscosity of liquids" was held in London on the 6th June, 1958. Summaries of the seven papers presented are given in detail.

358. Slope index.—An expression for viscosity-temperature characteristics. E. E. KLAMS, R. E. HERSH and M. J. POHORILLA, *Lubric. Engng.*, 1958, **14**, 439–447. Pennsylvania State University. As a replacement for the unsatisfactory Viscosity Index system used in the oil industry for representing viscosity–temperature characteristics, the authors support one based on the well-known A.S.T.M. slope m. For convenience the Slope Index (S.I.) is calculated as :

$$\text{S.I.} = (1 \cdot 5 - m) \times 1000$$

The advantages of the S.I. are illustrated with the aid of experimental data obtained for mineral oils and synthetic fluids over the temperature range −65 to +700°F. J.F.H.

359. Effect of pressure on viscosity of higher hydrocarbons and their mixtures. E. M. GRIEST, WAYNE WEBB and R. W. SCHIESSLER, *J. Chem. Phys.*, 1958, **29**, 711. Socony Mobil Laboratories Paulsboro, N.J., U.S.A. A rolling bulk method was used to measure the viscosity of seven pure hydrocarbons and their mixtures at pressures up to 3450 bars and temperatures of 37·8°C, 60·0°C, 98·8°C and 135°C. Aromatic aliphatic and cycloparaffinic types were used. The pressure-viscosity coefficient varies with structure and temperature. Mixtures behave very similarly to pure compounds of the same average structure and molecular weight, implying an additive viscosity function for the constituent groups. For saturated compounds at constant temperature Log η is proportional to

$$[(V_0/V)^4 - (V_0/V)^2]$$

where V_0 is the specific volume. E.B.A.

360. Study of the compressions of several high molecular weight hydrocarbons. W. G. CUTLER, R. H. MCMICKLE, W. WEBB and R. W. SCHIESSLER, *J. Chem. Phys.*, 1958, **29**, 727. Socony Mobil Laboratories, Paulsboro

N.J., U.S.A. Thirteen high purity hydrocarbon liquid and two hydrocarbon solids were used having molecular weights from 170 to 351. Pressures up to 10,000 bars and temperatures between 37·8 and 135·0°C were used. Pressure-volume isotherms could be fitted to the Tait equation or, above a certain pressure to the Hudleston equation. The effect of structure on compressibility is discussed. E.B.A.

361. Variations in the value of Reynolds number at the transition from streamline to turbulent flow. P. J. ISAAC, I. B. WILLIAMS and W. M. JONES, *Nature, Lond.*, 1959, **183**, 531–532. Department of Physics, University College, Aberystwyth. The flow of nitrogen and carbon dioxide through a porous copper disc and through a long copper tube over a range of pressures has been studied. The Reynolds numbers Re' for the two gases were found to differ, and that Re' for the carbon dioxide diminished as the mean pressure increased. It is suggested that these results are possibly due to energy transfers occurring in the gases at what appears to be the transition from streamline to turbulent flow in such a way that the flow is no longer isothermal. W.G.C.

362. Study of variation of dielectric relaxation time with solvent. C. R. K. MURTHY, *J. Sci. Industr. Res.*, 1958, **17B**, 441–444. Physics Dept., Andhra University, Waltair, India. Relaxation times of acetophenone, benzyl alcohol and aniline have been determined in dilute solutions in four non-polar solvents (cyclohexane, benzene, carbon disulphide and *n*-hexane). The variation of relaxation time with solvent has been discussed in the light of the new approaches made recently for modifying the Debye equation. Author

363. Ultrasonic studies on some aqueous solutions of electrolyte. K. SUBBA RAO and B. RAMACHANDRA RAO, *J. Sci. Industr. Res.*, 1958, **17B**, 444–447. Ultrasonic Laboratories, Andhra University, Waltair, India. The variation of ultrasonic velocity, adiabatic compressibility and apparent molal compressibility with molal concentration has been studied in the case of aqueous solutions of seven coloured salts. The experimental results have been examined in the light of the Debye-Hückel theory for electrolytes. Author

364. Resistance to flow in vascular beds. A. C. BURTON. *Nature, Lond.*, 1958, **182**, 1456–1457. Biophysics Laboratory, University of Western Ontario, London, Ontario, Canada. The resistance to flow in vascular beds is discussed in relation to "transmural pressure" and dilation of the vessels. The analogy between resistance to flow and ohmic resistance is also discussed with particular reference to the concept of "dynamic resistance" advocated by S. D. Carlill. W.G.C.

365. Flow in sewage treatment farms. S. C. BURGESS and A. F. GREEN, *Fluid Handling*, 1959, No. 108, 6–8. A report on a paper given at an Ordinary Meeting of the Institution of Civil Engineers in which radioactive tracers were used in full scale investigations of flow through and in sewage tanks.

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366. A three-dimensional motion of artesian waters. ST. A. GHEORGHITZA, *Arch. Mech. Stosowanej*, 1958, **10**, 607–615.

367. Nomogram : viscosity of liquid sulphur dioxide. D. S. DAVIS, *Chem. Process Eng.*, 1958, **39**, 367.

Section G

GENERAL

368. Evidence for permeability minima in low-pressure gas flow through porous media. D. M. GROVE and M. G. FORD, *Nature, Lond.*, 1958, **182**, 999–1000. Queen Mary College, University of London, Mile End Road, London, E.1. The flow of helium, neon and argon at 25°C through porous ceramics and through graphites is reported. Gas flow in a single capillary gives a linear relationship between the permeability K and the mean pressure of the gas $\bar{p}$ in the region of slip flow, which usually flattens at low pressures. In this work, though, marked permeability minima are obtained, which confirms earlier workers' observations. The results suggest that pore size distribution, rather than the mean pore radius, may be the factor which determined whether or not a minimum occurs.
W.G.C.

369. Some effects of the mixing process on the physical properties of dough. C. J. DEMPSTER and I. HLYNKA, *Cereal Chem.*, 1958, **35**, 483–488. Grain Research Laboratory, Board of Grain Commissioners for Canada, Winnipeg 2, Manitoba, Canada. Results based on Extensogram data for doughs mixed in nitrogen and in air showed that increasing mixing time produced a marked decrease in extensibility. Analysis of these data according to the structural relaxation procedure showed that mixing had very little effect on structural relaxation behaviour of dough, but the effect of atmospheric oxygen occluded during mixing was pronounced. The effect of mixing per se appears to be distinct from and independent of the effect of oxygen. It is suggested that mixing decreased the size of the flow unit in dough.
H.G.M.

370. Flour lipids and the bromate reaction. D. K. CUNNINGHAM and I. HLYNKA, *Cereal Chem.*, 1958, **35**, 401–410. Grain Research Laboratory, Board of Grain Commissioners for Canada, Winnipeg 2, Manitoba, Canada. The influence of the lipids of flour upon the bromate reaction in dough has been shown to be threefold ; prolonged mixing in the presence of lipids accelerates the subsequent bromate reaction ; in the absence of lipid the bromate action is depressed ; bromate reaction in doughs from defatted flours mixed in air or oxygen is depressed, presumably through concurrent removal of natural antioxidants in the lipid fraction.
H.G.M.

371. What's in a name (definitions of terms relating to the lubricating grease industry). Part II. W. K. EWBANK, *N.G.L.I. Spokeman*, 1958, **22**, 378–380. Cato Oil and Grease Company.

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J. Soil Sci.
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Kolloidnyĭ Zh.
Kolloidzschr.
Kunststoffe

Lab. Practice
Lubric. Engng.

Mod. Plast.

Nature, Lond.
Neftyanoe Khoz.
NLGI Spokesman
Nuovo Cim.

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Text. Res. J.
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Section A

THEORETICAL

372. Flow of real fluids. M. RAY, *J. Sci. Industr. Res.*, 1959, **18**A, 101–102. A summary of the presidential address given to the Section of Mathematics at the 46th Session of the Indian Science Congress. The mathematical approach to the theory of the flow of real fluids, and the derivation and limitations of the equations of motion and equations of state are discussed. Solutions recently obtained for some simple and special cases are considered. W.G.C.

373. Elastic wave propagation in fluids. A. K. DUTTA, *J. Sci. Industr. Res.*, 1959, **18**A, 102–104. A summary of the presidential address given to the Section of Physics at the 46th Session of the Indian Science Congress. A connected account of the work carried out in recent years on elastic wave propagation in fluids is given, and the anomalous experimental results obtained and the theoretical interpretations advanced by several workers are discussed with reference to the author's own findings. W.G.C.

374. On the general plane problem of plasticity and its geophysical significance. S. C. DAS, *Canad. J. Phys.*, 1959, **37**, 63–74. Dept. of Mines & Technical Surveys, Ottawa. The results obtained from the fault plane studies made in the Dominion Observatory show strong horizontal displacements in the focus of earthquakes. This indicates a marked deviation from the existing theories of geotectonics. To account mathematically for them, the study of the plane problem of plasticity is proposed using as yield condition a general functional relation between the stresses. The differential equations involved in the problem are of *non-linear* type. For solutions these are replaced by a different set of completely equivalent equations expressing variations along families of curves, known as *characteristics*, across which certain derivates may be discontinuous under suitable boundary conditions. M.F.C.

375. Virtual work, linear programming and plastic limit analysis. A. CHARNES, C. E. LEMKE and O. C. ZIENKIEWICZ, *Proc. Roy. Soc.*, 1959, **A251**, 110–116. Technological Institute, Northwestern University, Ill., U.S.A.

376. An example of minimum energy dissipation in viscous flow. D. G. CHRISTOPHERSON and D. DOWSON, *Proc. Roy. Soc.*, 1959, **A251**, 550–564. Dept. of Mechanical Engineering, Imperial College of Science and Technology. The problem of a heavy ball falling in a vertical tube, filled with a viscous liquid and having a diameter only slightly exceeding that of the ball, is discussed. J.R.J.

377. The stability of viscous flow between horizontal concentric cylinders. D. B. BREWSTER, P. GROSBERG and A. H. NISSAN, *Proc. Roy. Soc.*, 1959, **A251**, 76–91. Dept. of Textile Industries, The University, Leeds. The critical conditions for the formulation of Taylor vortices are considered. J.R.J.

378. The polymerization of styrene sensitized by molecules in the triplate state—I. The reaction between anthracene and styrene. V. S. ANDERSEN and R. G. W. NORRISH, *Proc. Roy. Soc.*, 1959, **A251**, 1–3.

379. Plane sliders of finite width. D. F. HAYS, *A.S.L.E. Trans.*, 1958, **1**, 233–240. Research Laboratories, General Motors Corporation, Detroit 2, Michigan. A system composed of two surfaces of finite width in relative motion and separated by a layer of lubricant is analysed. The various properties of the system which emerge are plotted in the form of non-dimensional graphs. A.D.B.

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Section B

INSTRUMENTS AND TECHNIQUES

380. Modification of a cone-plate viscometer for direct recording of flow curves. WALTER H. BAUER, ALFRED P. FINKELSTEIN, CHARLES A. LAROM and STEPHEN E. WIBERLEY, *Rev. Sci. Instrum.*, 1959, **30**, 167–169. Department of Chemistry, Rensselaer, Polytechnic Institute, Troy, New York. A control device for shear rate acceleration of the cone-plate viscometer has been designed so that flow curves can be obtained automatically using an $x-y$ recorder. A description of the device and flow curves for a typical grease are given. H.J.R.

381. Measurement of absolute viscosities of liquids and the influence of surface tension. P. R. RAO and N. SUBRAMANIAN, *J. Sci. Industr. Res.*, 1959, **18B**, 170–171. Laxminarayan Institute of Technology, Nagpur University, Nagpur, India. This note presents an application of the method of dimensional analysis to compute the influence of surface tension in the measurement of viscosities of liquids. Allowance has been made for the effects of unequal drainage, variation in working volume, and the kinetic energy of the liquid under study. Results obtained with water and benzene employing B.S.S. Ostwald viscometer No. 0 are quoted. W.G.C.

382. Viscosity measurements above 2000 °C. *Instrum. Pract.*, 1958, **12**, 973. A note on the use of the oscillating cup method for measuring very low viscosities under particularly difficult conditions of temperature and chemical reactivity. The work is being done at the National Bureau of Standards. M.F.C.

383. Some applications of viscometry to drying oil research. G. H. HUTCHINSON, *J. Oil Col. Chem. Ass.*, 1959, **42**, 283–301. John M. Hamilton & Co. Ltd., Humber Oil Works, Wincolmlee, Hull. η-Measurements for studying thermal polymerization of drying oils and poly-condensations of oil based surface-coating media are discussed. A high temperature viscometer is described. W.H.B.

384. Direct-reading viscometer. *Instrum. Pract.*, 1958, **12**, 968. A note from the National Bureau of Standards on a device consisting essentially of a capillary and an orifice in series. If the total loss in head is kept constant, the loss across the orifice is a function of kinematic viscosity. M.F.C.

385. Automatic instrument for accurate measuring of the viscosity of liquids. V. N. DUDARCHIK, S. S. URAZOVSKII and P. A. CHERNYAVSKII. *Zavodskaya Lab.*, 1958, **24**, 1278–1279. [Russian]

386. On the application of [Volarovich's] rotary viscometer to rheological investigations of systems with rapidly changing structural properties. M. M. GURVICH, *Kolloidnyĭ Zh.*, 1959, **21**, 164. Institute of Chemistry, Azerbaijan S.S.R., Baku. Thixotropic drilling muds can be tested with only slight modifications to the apparatus if structure is well broken down. Non-thixotropic muds are too variable. Results are compared with those from another standard viscometer. [Russian] English abstract. G.W.S.B.

387. Flow testing of viscoelastic materials. Design and calibration of the Roberts–Weissenberg Model R.8 rheogoniometer. A. JOBLING and J. E. ROBERTS, *J. Polym. Sci.*, 1959, **36**, 421–431. Ernest Oppenheimer Laboratory, Dept. of Colloid Science, University of Cambridge and Armament Research & Development Establishment, Ministry of Supply, Fort Halstead, Sevenoaks, Kent. The rheogoniometer is an instrument for the analysis in space and time of the complete stress distribution in a viscoelastic liquid subjected to shear. A greatly improved design is described which provides, as alternatives, unidirectional or oscillatory laminar shear, a superposition of the two, and a predetermined acceleration to (or deceleration from) the first type of motion. The speed and accuracy of measurement are also enhanced in the new design. E.H.A.

388. Characterisation of molecular weight distributions by a viscometric method. P. F. ONYON, *Nature, Lond.*, 1959, **183**, 1670–1671. Dept. of Chemistry, College of Technology, Birmingham. The ratio of weight-average to number-average molecular weights (M_w/M_n) may be obtained from individual determinations of M_w and M_n, the percentage error in the ratio being approximately the sum of the errors of these determinations. The uncertainty as to the magnitude of this error is reduced in the proposed single technique (based on the measurement of limiting viscosity numbers alone) in which the viscosity-average molecular weights are determined of monodisperse polymer in both a good solvent and a poor solvent for the polymer. W.G.C.

389. A method for evaluating the plastic properties of highly swelling coals. J. BANDOPADHYAY, S. SARKAR and N. N. DAS GUPTA, *J. Sci. Industr. Res.*, 1959, **18B**, 116–118. Central Fuel Research Institute, Jealgora, Bihar, India. The plastic properties of highly swelling coals, determined experimentally by the present methods, are not accurate due to excessive frothing of the coals. A new method, which enables the determination of plastic properties of such coals accurately, is reported.

The coal sample is mixed with increasing proportions of an inert powder and tested in a Gieseler plastometer. From extrapolation of the graph of percentage inert powder against log maximum fluidity can be derived the correct characteristic values of the coal sample. W.G.C.

390. Measurement of the tensile strength of brittle materials. R. BERENBAUM and I. BRODIE, *Brit. J. Appl. Phys.*, 1959, **10**, 281. N.C.B. Mining Research Establishment, Isleworth, Middlesex, England. A bending test, an indentation test and a test in which discs are compressed diametrically are investigated and compared with the conventional pull method for specimens of various brittle materials. The methods give results in reasonable agreement apart from the bending test in which the variability is attributed to sensitivity to surface conditions. G.M.J.

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391. Tensile testing machine for microscopic specimens. D. M. MARSH, *J. Sci. Instrum.*, 1959, **36**, 165–169. Tube Investments Research Laboratories, Hinxton Hall, Cambridge. The problems of the mechanical testing of whiskers and thin films having gauge lengths down to 0·2 mm and cross-sections as low as 8×10^{-7} mm² are discussed. A machine is described which gives load–strain curves for such specimens with minimum load increments of 0·5 mg force and with extension readings repeatable to 0·019 μ. A torsion balance applies and measures the load and the strain is obtained by a null method using a marker and a special optical arrangement in a projection microscope. A number of special design features are incorporated to ensure high stability. Author

392. A contribution to the determination of elongation for small sample lengths. K. GEITEL, *Faserforschung*, 1959, **10**, 204–208. Institut für Textiltechnologie der Chemiefasern, Rudolstadt-Schwarza, Germany. Clamping errors are considered. [German]

393. On the examination of mechanical properties with strength testers for textile fabrics. M. LUXA, *Faserforschung*, 1959, **10**, 175–182. Institut für Textiltechnologie der Chemiefasern, Rudolstadt-Schwarza, Germany. Equations based on simple spring and dashpot models are used to investigate the mechanical coupling between a viscoelastic test piece and the apparatus concerned, allowance being made for the inertia of the clamps. Experiments with constant rate of loading and with constant rate of extension are considered. [German] A.S.L.

394. Physico-technical examination of fibres. W. FRENZEL, H. FRÜCHT and G. HAHN, *Faserforschung*, 1959, **10**, 192–203. Institut für Technologie der Fasern, Dresden, Germany. A new extensometer working at constant elongation speed is described and its performance is compared with that of other extensometers. Tension is measured electronically. [German] A.S.L.

395. A systematic account of dynamical testing methods for high polymer solids—IV. The dynamic bending test. V. The dynamic shearing stress. F. WINKLER, *Faserforschung*, 1959, **10**, 183–187, 209–211. Institut der Faserstoff-Forschung, Teltow-Seehof, Germany. Brief compilations

containing eighty-two and sixteen references to published methods are given. [German]

396. Vacuum fatigue-apparatus. N. J. WADSWORTH, *J. Sci. Instrum.*, 1959, **36**, 274–277. Royal Aircraft Establishment, Farnborough, Hants. An apparatus is described in which it is possible to anneal metal specimens in the form of flat sheets *in vacuo* and then fatigue them *in vacuo* or in any desired atmosphere without intermediate exposure to air. An electromagnetic drive is used to fatigue them in reversed bending between constant strain limits at 100 c/s. An automatic cut-out stops the test as soon as a large crack appears. Some typical results for high-conductivity copper are shown. Author

397. Developments of photoelasticity. R. E. D. BISHOP, *Nature, Lond.*, 1959, **183**, 1495–1496. A brief summary of a meeting held at University College, London, to commemorate the collaboration between Professors E. G. Coker and L. N. G. Filon which started in 1909. Recent developments resulting from their work are briefly reviewed. W.G.C.

398. Resistance strain gauges of low temperature sensitivity. G. R. HIGSON, *J. Sci. Instrum.*, 1959, **36**, 157–159. The Fairey Aviation Co. Ltd., Hayes, Middx. Strain gauges manufactured from a series combination of Nichrome and Advance wires may be used in quarter-bridge circuits to measure static strains where the temperature is slowly varying. The average temperature drift corresponds to 20 lb/in. × °C on steel and 2·5 lb/in. × °C on dural and the sensitivity drop is less than 5 per cent. up to 250 °C. When used in a full-bridge circuit, the drift should be negligible. Author

399. Electric network analog study of viscous flow normal to parallel evenly spaced cylinders. J. LOWEN SHEARER, *Textile Research J.*, 1959, **29**, 467. Massachusetts Institute of Technology, Cambridge, Massachusetts. A resistive network is set up which gives an approximate solution of the problem of flow past an array of infinitely long parallel cylinders whose centers are on an hexagonal lattice. D.W.S.

Section C

METALS AND OTHER SOLIDS

400. Improvement of the fatigue strength of notched specimens by artificially induced residual stresses. T. R. GURNEY, *Nature, Lond.*, 1959, **183**, 883–884. British Welding Research Association, Abington Hall, Abington, Cambridge. Test strips of mild steel with a short longitudinal stiffening gusset fillet welded centrally on each face were tested under axial loading with a pulsating tension load cycle. The upper limit stress could be increased by compressing the test strips near the ends of the fillets to an average compressive stress of 58·5 tons/in^2. It is concluded that specimens having clearly defined probable points for the initiation of fatigue failure can have their fatigue strength increased by compressing an area adjacent to the notch to such an extent that residual stresses are induced. W.G.C.

401. Fatigue properties of ternary aluminium–zinc–magnesium alloys. I. J. POLMEAR, *Nature, Lond.*, 1959, **183**, 1388–1389. Australian Defence Scientific Service (Aeronautical Research Laboratories), Box 4331, G.P.O., Melbourne. Cyclic stressing of age-hardened aluminium alloys causes deformation to become progressively more localized and the dispersed precipitate in these regions may become unstable. The effect of the magnesium : zinc ratio on the fatigue strength of these alloys is reported, and the high fatigue strength obtained with one alloy is attributed to a critical value of this ratio. The data are insufficient to indicate that a reduction in the mobility of dislocation is due to the interaction of the excess magnesium atoms with the dislocations. W.G.C.

402. Mechanism of stress–corrosion cracking in the AZ31B magnesium alloy. H. L. LOGAN, *J. Res. Nat. Bur. Stand.*, 1958, **61**, 503–508. Cracking was found to be an electrochemical process, dependent on the rate of strain. It is postulated that cracks develop if the protective film on the metal surface is ruptured at a greater rate than it is repaired by corrosion. M.F.C.

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403. Activation energy for creep of tin. L. G. BONAR and G. B. CRAIG, *Canad. J. Phys.*, 1958, **36**, 1445–1449. Dept. of Metallurgical Engineering, University of Toronto, Toronto, Ontario. Constant stress creep tests on steady state creep, with temperature cycling, have yielded the figure of 9000 cal/g-atom for creep in high purity tin between 300 and 350 °K. M.F.C.

404. Elastic constants of indium antimonide from 4·2 °K to 300 °K. L. J. SLUTSKY and C. W. GARLAND, *Phys. Rev.*, 1959, **113**, 167–169. Department of Chemistry, University of Texas, Austin, Texas. The adiabatic elastic constants of a single crystal of indium antimonide have been measured by an ultrasonic pulse technique in which 10 Mc/s acoustic waves were employed. The elastic constants extrapolated to 0 °K are, in units of 10^{12} dynes/cm^2, $C_{11}=0{\cdot}6918$, $C_{12}=0{\cdot}3788$ and $C_{44}=0{\cdot}3132$. A Debye characteristic temperature, of 205 °$\pm$2 °K at 0 °K was calculated from these values of the elastic constants. Author

405. On the viscosity of steel enamels. K. P. AZAROV and S. B. GRECHANOVA, *Kolloidnyĭ Zh.*, 1959, **21**, 144. Enamels Laboratory, Ordzhonikidze Novocherkasskiĭ Polytechnic Institute. Characteristic differences in viscosity between boron-free and titanium–boric enamels are much emphasized on addition of iron oxide : boron-free viscosity rises, whereas boron enamel viscosity falls. Relationships between these viscosities on blister formation are discussed. [Russian] English abstract. G.W.S.B.

406. Relationship between strength and porosity for coal compacts. D. J. MILLARD, *Brit. J. Appl. Phys.*, 1959, **10**, 287. N.C.B. Central Research Establishment, Cheltenham. The strength of a coal powder compact was found to be a single valued function of the porosity which could not be explained by treating the pores as if they only reduced the load bearing area. An explanation is given in terms of the development of contacts between particles and of the changing action

of the pores as stress magnifiers. A strength : porosity relationship is deduced which is shown to give a good representation of the experimental data. F.M.J.

407. The dependence of the elastic behaviour of coal on the microcrack structure. N. B. TERRY, *Fuel*, 1959, **38**, 125. N.C.B. Mining Research Establishment, Isleworth, Middlesex, England. Using acoustic techniques, the elastic wave velocity perpendicular to the bedding plane in various coals was found to be markedly dependent upon external stress. Together with the effect of impregnation and comparisons with models consisting of piles of thin ebonite plates, these observations are taken as evidence of a system of flat microscopic cracks lying parallel to the bedding plane. It is concluded that this structure, not crystallinity, is responsible for the transverse elastic symmetry observed. G.M.J.

408. On the mechanism of the compression of coke, causing its compaction and cracking.—I. On the compression of coke and its settlement. B. A. ONUSAITIS and V. F. KOZLOVA, *Kolloidnyi Zh.*, 1959, **21**, 216. N. P. Chizhevskii Laboratory of Metallurgy of Fuels, Institute of Mineral Fuels, Academy of Sciences, U.S.S.R. Coke is caused to contract by capillary forces resulting from volatilization of materials filling the pores of the gel-like framework. This type of compression does not occur in semi-coke, but can be induced by addition of high-boiling substances which volatilize towards the end of the coking process. [Russian] English abstract. G.W.S.B.

409. Evaluation of tensile compressive, torsional, transverse, and impact tests and correlation of results for brittle cements. M. J. KERPER, L. E. MONG, M. B. STIEFEL and S. F. HOLLEY. *J. Res. Nat. Bur. Stand.*, 1958, **61**, 149–170. Static tests were made on cermets of five different compositions. These brittle materials broke either at a limiting tensile strain or at a limiting shear stress. M.F.C.

410. Errors caused by partial drying of hardened Portland cement during testing. K. M. ALEXANDER, *Nature, Lond.*, 1959, **183**, 885–886. Stanford Research Institute, Menlo Park, California, U.S.A. The modulus of rupture of Portland cement paste prisms of 0·5 in. square cross-section is shown to vary with the time of exposure to air. For specimens tested while immersed in a water-bath, the mean modulus of rupture obtained was 1960 lb/in². With specimens exposed for more than 1 min the modulus was 1010 lb/in². Similar results have been obtained with larger specimens. W.G.C.

Section D

POLYMERS, ELASTOMERS AND VISCOELASTIC MATERIALS

411. Crystallization kinetics and mechanical properties of polyethylene. R. BUCHDAHL, R. L. MILLER and S. NEWMAN, *J. Polym. Sci.*, 1959, **36**, 215–231. Plastics Division, Monsanto Chemical Co., Springfield, Massachusetts, U.S.A. The kinetics of crystallization of a branched poly-

ethylene were studied dilatometrically, spectroscopically and microscopically at small degrees of supercooling (0–10 °C). Results from the different experimental techniques are in general agreement with theory and with one another, but reveal small variations which are significant. Processes occurring during crystallization are considered and the dependence of dynamic mechanical properties upon thermal history is qualitatively explained. E.H.A.

412. Comments on intrinsic viscosity–weight-average molecular weight relationships for polyethylene. R. CHIANG, *J. Polym. Sci.*, 1959, **36**, 91–103. Research Centre, Hercules Powder Co., Wilmington, Delaware, U.S.A. The poor agreement between different published relationships, connecting intrinsic viscosity with weight-average molecular weight for high-density polyethylene, is attributed variously to polydispersity, incorrect dissymmetry correction and inadequate solution clarification. Results on fractionated and unfractionated samples support these conclusions and indicate the need to study fairly narrow fractions. E.H.A.

413. Relations among melt viscosity, solution viscosity, molecular weight and long-chain branching in polyethylene. L. D. MOORE, Jr., *J. Polym. Sci.*, 1959, **36**, 155–172. Research Laboratories, Tennessee Eastman Co., Division of Eastman Kodak Co., Kingsport, Tennessee, U.S.A. A new theory is presented to account for the fact that branched polyethylenes have lower melt viscosities than linear polyethylenes. The reduction in viscosity is attributed to the presence of long-chain branches which help co-ordinate the movement of the various segments. A predicted linear relation between the logarithm of the melt index and the intrinsic viscosity in an ideal solvent is confirmed experimentally. Difference in solution viscosity in samples of the same melt viscosity are attributed to differences in the solvent expansions factor. E.H.A.

414. Long term behaviour of polyethylene and PVC pipes. H. NIKLAS and K. EIFFLAENDER, *Kunststoffe*, 1959, **49**, 3, 109. Long term tests on normal and low pressure polyethylene pipes give results which when plotted as log/log functions produced curves very similar to each other, decrease in mechanical strength being gradual at first but later more rapid. The curves for rigid PVC were more varied, being convex, concave or linear. Changes in the shape of curve were in this case due to the effects of contact with fluids rather than the beginning of brittle fracture. [German] E.B.

415. Extrapolation, safety factors and maximum working pressures relating to polyethylene and PVC pipes. K. RICHARD and R. EWALD, *Kunststoffe*, 1959, **49**, 3, 116. Using Ziegler polyethylene, the graphic extrapolation of long term tensile test curves is explained and the correlation method of Larson and Miller discussed. Consideration of the long term tensile strength and elongation leads to a maximum working pressure of 710 lb/in² at 20 °C for Ziegler polyethylene pipe. The problems involved in specifying maximum working pressures for PVC pipes are discussed. [German] E.B.

416. Durability and elasticity of polyvinyl chloride gel plastisols. I. N. POP and I. A. MAYER, *Revista Chim., Roum*, 1958, **9**, 557–560 (via *J. Appl. Chem., Abstracts*, 1959, **9**, 1–521). Mechanical and physical characteristics at different degrees of plasticization are examined. [Italian] English summary. W.G.C.

417. Detection of crystallinity changes in copolymers of vinylidene chloride and alkyl acrylates by torsional modulus measurements (letter). G. R. RISER, W. S. PORT, L. P. WITNAUER, *J. Polym. Sci.*, 1959, **36**, 543–545. Eastern Regional Research Laboratory, Eastern Utilization Research & Development Division, United States Dept. of Agriculture, Philadelphia 18, Pennsylvania, U.S.A. Measurements of torsional modulus, made at 5° intervals during the heating-up of amorphous specimens, were used to follow the onset and progress of crystallinity in these materials. The results are discussed. The method appears to be more sensitive than X-ray diffraction for the detection of small amounts of crystallinity. E.H.A.

418. Velocity of the propagation of sound and its internal dissipation in polymethacrylates. E. BUTTA, *Ann. Chim., Italy*, 1958, **48**, 802–810. [Italian]

419. Mechanical properties of poly-*n*-octyl methacrylate at low frequencies and in creep ; entanglements in methacrylate polymers. J. W. BERGE, P. R. SAUNDERS and J. D. FERRY, *J. Colloid Sci.*, 1959, **14**, 135–146. Department of Chemistry, University of Wisconsin, Madison, Wisconsin. The storage modulus and loss tangent have been measured between 0·06 and 1·6 c/s at temperatures from 54° to 140 °C for a fractionated poly-*n*-octyl-methacrylate [mol. wt. $3{\cdot}62\times10^{6}$]. Creep measured at 120 °C for times up to 2000 sec. The usual method of reduced variables could not be applied. An additional reduction is proposed to give agreement with results previously obtained with poly-*n*-hexyl and *n*-butyl methacrylate. R.B.B.

420. Dynamic mechanical properties of poly-*n*-docosyl methacrylate. P. R. SAUNDERS and J. D. FERRY, *J. Colloid Sci.*, 1959, **14**, 239–243. Department of Chemistry, University of Wisconsin, Madison, Wisconsin. The real and imaginary components of the complex compliance have been measured between 24 and 100 c/s at 59·0° and 65·2 °C. The monomeric friction coefficient has been estimated. Conclusions are drawn about the degree of entanglement of a methacrylate polymer and it is concluded that the number of strands per cubic centimetre depends only on the concentration of chain backbones regardless of whether solvent or side groups are present. R.B.B.

421. Dynamic mechanical properties and creep of poly-*n*-dodecyl methacrylate. S. F. KURATH, T. P. YIN, J. W. BERGE and J. D. FERRY, *J. Colloid Sci.*, 1959, **14**, 147–160. Department of Chemistry, University of Wisconsin, Madison, Wisconsin. Real and imaginary components of the complex compliance have been measured between 24 and 3600 c/s at

temperatures from −40 °C to +45 °C for a fractionated polymer [mol. wt.$=0{\cdot}95\times10^6$]. Creep compliance was measured between −30 ° and +30 °C. An anomaly at −28 °C was attributed to crystallization of the side groups. Friction coefficients for *n*-alkyl methacrylate polymers have been revised and are shown to be satisfactorily related to differences in free volume using either the treatment of Dannhauser *et al.* or Fujita and Kishimoto. R.B.B.

422. Rheology of poly*iso*butylene–III. Elastic recovery, non-Newtonian flow and molecular weight distribution. H. LEADERMAN, R. G. SMITH and L. C. WILLIAMS, *J. Polym. Sci.*, 1959, **36**, 233–257. National Bureau of Standards, Washington 25, D.C., U.S.A. Moments of the molecular weight distribution were measured in the equilibrium ultracentrifuge for two rough fractions of poly*iso*butylene. Flow and elastic recovery measurements were made on these materials and on a series of blends. The relationships between the measured quantities are discussed and shown to disagree with the results of molecular theories. E.H.A.

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423. An investigation, with the Weissenberg rheogoniometer, of the stress distribution in flowing poly*iso*butylene solutions at various concentrations and molecular weights. A. JOBLING and J. E. ROBERTS, *J. Polym. Sci.*, 1959, **36**, 433–441. Ernest Oppenheimer Laboratory, Dept. of Colloid Science, University of Cambridge and Armament Research and Development Establishment, Ministry of Supply, Fort Halstead, Sevenoaks, Kent. The flow properties of a series of titration solutions of poly*iso*butylene were examined with the Weissenberg rheogoniometer. The general form of the stress distribution in laminar flow is the same as observed in other viscoelastic materials, the main phenomenon being an additional normal tension in the direction of flow. The effects of rate of shear and of polymer concentration and molecular weight on this stress distribution are investigated and discussed. E.H.A.

424. Influence of velocity of gradient on the viscosity of polystyrene solutions. G. M. GUZMÁN and J. M. G. FATOU, *J. Polym. Sci.*, 1959, **35**, 441–463. Sección de Fisicoquimica Macromolecular, Departmento de Plásticos del Patronato Juan de la Cierva (C.S.I.C.), Serrano 119, Madrid, Spain. The flow behaviour of polystyrene samples of different molecular weights in different solvents has been studied using capillary viscometers. Intrinsic viscosities corrected for shear effects in the usual manner still showed considerable divergence. The results are explained in terms of non-Newtonian flow, and extrapolation of the results to zero shear rate is considered to be the safest method for obtaining the intrinsic viscosity. A method for this is described, giving results up to 60 per cent higher than usual. The influence of solvent and molecular weight on the shear effect is also discussed. E.H.A.

425. The polymerization of styrene sensitized by molecules in the triplate state.—II. Kinetics and mechanism. R. G. W. NORRISH and J. P. SIMONS, *Proc. Roy. Soc.*, 1959, **A251**, 4–26.

426. Thermodynamic functions of the swelling of cross-linked polystyrenesulphonic acid resins.—Part 1. Resins in the hydrogen state. S. LAPANJE and D. DOLAR, *Z. Phys. Chem. Frankf.*, 1958, **18**, 11–25.

427. Determination of flow properties of thermosetting moulding powders —Introduction to Draft German Standard DIN 53478. C. M. VON MEYSENBUG, *Kunststoffe*, 1959, **49**, 130.

428. Stress relaxation studies of scission in rubber vulcanizates. A. MERCURIO and A. V. TOBOLSKY, *J. Polym. Sci.*, 1959, **36**, 467–473. Frick Chemical Laboratory, Princeton University, Princeton, New Jersey, U.S.A. Oxidative scission in cross-linked rubbers of five different chain structures was studied by the method of stress-relaxation. With sulphur as the cross-linking agent, rates of scission varied significantly from one vulcanizate to another. On the other hand, for natural rubber, GR-S, and butyl rubber, change to a non-sulphur vulcanizing system made little difference to the scission rate. It is concluded that for these polymers scission occurs primarily along the network chain and not at the cross-linked site. E.H.A.

429. Estimation of chain fracture during the cross-linking of rubber hydrocarbons by high-energy radiation. L. MULLINS and D. T. TURNER, *Nature, Lond.*, 1959, **183**, 1547–1548. British Rubber Producers' Research Association, 48, Tewin Road, Welwyn Garden City, Herts. The ratio of fractures to cross-links, β, has usually been estimated from studies of the solubility of irradiated polymers. A more recent method, using data from simple extension–strain measurements, has been developed. Values of β obtained by these two methods are discussed, together with those found from measurements of stress relaxation. W.G.C.

430. Chemical reactions induced by polymer deformation. W. F. WATSON, *I.R.I. Trans.*, 1958, **34**, 237–247.

431. Effect of deformation on the orientation of high polymers. V. YE. KOTINA and I. N. SHELEPEN, *Zhur. fiz. Khim.*, 1958, **32**, 2247–2250. [Russian] English summary.

432. Deformation and orientation of linear macro-molecules in the laminar flow. A. PETERLIN, *Bull. Res. Council Israel*, A7, 1–8, 1957.

433. Viscosity of high polymers : random walk of a group of connected segments. H. EYRING, T. REE and N. HIRAL. *Proc. Nat. Acad. Sci., Wash.*, 1958, **44**, 1213–1217.

434. Study of the transition phenomena of chain polymers by the photoelastic method. M. KANEKO, *J. Phys. Soc. Japan*, 1958, **13**, 1324–1327.

435. Dynamic mechanical properties of high polymers at low temperatures. A. E. WOODWARD and J. A. SAUER, *Fortschr. Hochpolym.-Forsch.*, 1958, **1**, 114–158.

436. Rheological interpretation of the mechanism of crease recovery of fibre. HIROSHI SOBUE and KENKICHI MURAKAMI, *Textile Research J.*, 1959, **29**, 251. Faculty of Engineering, Tokyo University, Japan, and Textile Research Institute of Japanese Government, Yokohoma, Japan. A Voigt model representing the creep of a fibre was used to predict the behaviour of a fibre after bending. D.W.S.

437. Ultrasonic velocity and adiabatic compressibility in polyelectrolyte solutions. JUNKICHI SOHMA, *J. Polym. Sci.*, 1959, **35**, 429–440. Physics Laboratory, Hokkaido Gakugei University, Hakodate, Japan. Ultrasonic velocity and adiabatic compressibility were measured in polyelectrolyte solutions as functions of concentration and temperature. The rates of change of these two quantities with concentration each pass through a maximum at low concentration in pure aqueous solution but these maxima disappear if KCl solution is added. The ultrasonic velocity increases with increasing temperature, whilst the adiabatic compressibility falls. The results are explained qualitatively in terms of Oosawa's theory of polyelectrolyte solutions. E.H.A.

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438. Stress relaxation and diffusion in keratin. J. E. ALGIE, *J. Polym. Sci.*, 1959, **35**, 535, 536. Wool Textile Research Laboratories, Commonwealth Scientific and Industrial Research Association, Ryde, N.S.W., Australia. Continuous record was made of the stress in stretched horsehair fibres during cyclic variation of the ambient humidity. The differences observed between an ordinary fibre and a silicone-covered fibre lead to the conclusion that the stress-relaxation is in part due to the inward diffusion of water vapour and the consequent weakening of bonds.
E.H.A.

439. First step in the swelling of gelatin with water. Parts 3, 4 and 5. C. WINTHER, *Acta Chem. Scand.*, 1958, **12**, 1634–1642, 1643–1651, 1652–1656.

440. The elastic properties of elastin. C. A. HOEVE and P. J. FLORY, *J. Amer. Chem. Soc.*, 1958, **80**, 6523–6526. Department of Chemistry, Cornell University, Pittsburgh, Pa. Force–temperature measurements have been carried out on elastin (ox ligamentum nuchae) held at fixed elongation and immersed in glycol–water (3 : 7) mixture. The equilibrium degree of swelling of elastin in this mixture is independent of temperature, and the retractive force is directly proportional to the absolute temperature. It follows that $(\partial E/\partial L)_{TV}=0$ for elastin and hence that the internal energy of the elastin chain is independent of its conformation. Contrary to previous studies on elastin, in which the influence of changes of swelling with temperature were overlooked, the thermoelastic behaviour offers no indication whatever for crystallization on stretching at any elongation. The shape of the stress–strain curve is explained in terms of the morphology of native elastin ; the abrupt rise in stress at high elongations is attributed to straightening out of the initially curled fibres of collagen which are associated with the native elastin. W.H.B.

441. Stress relaxation of non-electrolytic thermo-reversible gels. Concentration dependence of distribution function of relaxation times. Poly-(vinyl alcohol)–glycerol–water gels. K. ARAKAWA, *Bull. Chem. Soc. Japan*, 1958, **31**, 842–845.

442. The degree of polymerization and its distribution in cellulose rayons—Part VIII. The influence of degree of polymerization and molecular orientation on the mechanical properties of molecularly homogeneous monofilaments. R. J. E. CUMBERBIRCH and W. G. HARLAND, *J. Text. Inst.*, 1959, **50**, T311. British Cotton Industry Research Association, Shirley Institute, Didsbury, Manchester, 20. Fractions of secondary cellulose acetate were spun into monofilaments and then stretched and saponified to cellulose filaments. The birefringence, the tenacity and the breaking extension of each filament was then measured. D.W.S.

443. The sorption effect of cellulose trinitrate in capillary viscometry. M. M. HUQUE, M. FISHMAN and D. A. I. GORING, *J. Phys. Chem.*, 1959, **63**, 766. The Pulp and Paper Research Institute of Canada and McGill University, Montreal, Canada. Dilute solutions of cellulose trinitrate in ethyl acetate or acetone were found to show a sudden increase in η_{sp}/c as the concentration was decreased. D.W.S.

444. Swelling and elasticity of irradiated polydimethylsiloxanes. L. E. ST. PIERRE, H. A. DEWHURST and A. M. BUECHE, *J. Polym. Sci.*, 1959, **36**, 105–111. General Electric Research Laboratory, Schenectady, New York, U.S.A. The kinetic-theory elastic modulus of polydimethylsiloxanes cross-linked by high energy electrons has been redetermined cryoscopically and checked by measurement of the amount of gas evolved during irradiation. The value found, $G=2{\cdot}5\pm0{\cdot}4$, is significantly different from that previously reported. Swelling and equilibrium tension measurements on the cross-linked materials are also reported which accord well with theory. E.H.A.

445. The experimental check of theories of the viscosities of solutions. W. PHILIPPOFF and F. H. GASKINS, *J. Phys. Chem.*, 1959, **63**, 985. The Franklin Institute Laboratories for Research and Development, Philadelphia, Pa. The viscosity of poly-γ-benzyl-L-glutamate, has been measured in two solvents, *m*-cresol and dichloroacetic acid. Solutions of this polymer are practically monodisperse and this fact has been used to test theoretical predictions about the change of viscosity with rate of shear at low rates of shear for monodisperse systems. D.W.S.

446. The molecular weight of insoluble sodium metaphosphate. ULRICH P. STRAUSS and JEAN W. DAY, *J. Amer. Chem. Soc.*, 1959, **81**, 79–80. School of Chemistry of Rutgers, The State University, New Brunswick, N.J. The molecular weight of an "insoluble" sodium metaphosphate, $NaPO_3H$, was determined from intrinsic viscosity measurements in aqueous lithium bromide. The necessary intrinsic viscosity–molecular weight relationships were obtained from viscosity measurements of several potassium Kurrol salts whose molecular weights ranged from 220,000 to 1,320,000. The results establish $NaPO_3H$ as a long-chain polyphosphate with a molecular weight of at least 280,000. W.H.B.

447. Microwave absorption and molecular structure in liquids—XXVII. The mutual viscosities and dielectric relaxation times of several polar aromatic compounds in solution. DONALD A. PITT and CHARLES P. SMYTH, *J. Amer. Chem. Soc.*, 1959, **81**, 783, 786. The Frick Chemical Laboratory, Princeton University, New Jersey. The viscosities of dilute solutions of seven polar solutes in two non-polar solvents have been measured at 20, 40 and 60 °C, and the slopes of the viscosity–concentration plots have been used to calculate the mutual viscosities. The use of these values in an equation developed by Hill for the calculation of the relaxation times of the solutions gives values considerably higher than the observed. Author

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Section E

PASTES AND SUSPENSIONS

448. Application of the principle of similarity to calculations of flow processes of plastic greases in tubes. A. A. MAMAKOV, N. V. TYABIN and G. V. VINOGRADOV, *Kolloidnyi Zh.*, 1959, **21**, 208. Kirov Chemical Technological Institute, Kazan. Two methods have been proposed for the generalization of experimental data on the flow of plastic lubricants in tubes, in the form of a relationship between the coefficient of resistance of the tubes and the generalized Reynolds number. The method of variable effective viscosity consists in determining the generalized Reynolds number from the value of the local effective viscosity for the layer adjacent to the tube wall. The method of constant parameters consists in approximating the flow curve by means of straight lines corresponding to the Shvedov–Bingham equation and determining the generalized Reynolds number from the parameters of the visco-plastic flow. An expression has been found for the resistance coefficient of the tube in terms of the generalized Reynolds number. It has been shown that hydraulic methods based on approximating the flow curves of plastic lubricants in rotary viscometers may be used for calculating the pressure head loss in the flow of plastic lubricants in tubes. [Russian] English abstract. Author

449. Yield points of lubricating greases D. W. CRIDDLE and J. L. DREHER, *NLGI Spokesman*, 1959, **23**, 97–100. California Research Corporation. Five methods were used to find the yield points of seven greases. From these experiments it is shown that the yield point of a lubricating grease depends to a large extent upon the type of deformation. It was also concluded that the measured yield stress of a grease depends also on the rate of deformation and the work history of the sample. A.D.B.

450. Rheopectic grease composition. U.S. Patent 2846394. L. C. BRUNSTRUM and H. J. LIEHE, *Lubric. Engng*, 1959, **15**, 37. Standard Oil Company, U.S.A. A composition comprising essentially a mineral oil and 1 to 3·5 per cent of lithium hydroxystearate, the soap being in the form of particles 0·1 to 0·7μ in length. It is formed by chilling the soap solution to about 100 to 150 °F, homogenizing, reheating to 150 to

250 °F and diluting to the required soap concentration. The grease is normally fluid but sets up to a higher consistency after mechanical working. J.F.H.

451. Comparison of temperature effects on the flow properties of greases in capillary and cone and plate viscometers. W. H. BAUER, A. P. FINKELSTEIN, D. O. SLUSTER and S. E. WIBERLY, *NLGI Spokesman*, 1959, **23**, 15–24. Rensselaer Polytechnic Institute. Flow properties of greases at temperatures between 0 °C and 50 °C obtained with a capillary viscometer are compared with the results obtained by means of an automatically recording cone and plate viscometer. The results showed that the values of apparent viscosity obtained using the cone and plate viscometer are lower than those obtained using the capillary viscometer. The energies of activation of viscous flow calculated in the two cases also differ. These results are interpreted in terms of differing amounts of destruction of the various structural elements in the grease when it is sheared in the two types of viscometer. A.D.B.

452. The rheological properties of bitumens and tars. E. N. THROWER, *J. Inst. Petrol.*, 1959, **45**, 80–93. Road Research Laboratory, D.S.I.R. Harmondsworth, Middlesex. The stresses likely to be encountered in road surfaces are discussed. The rheological properties of tars and bitumens at high and low temperatures are then discussed in detail. A brief discussion of the brittle properties of bitumens at low temperatures is given. A.D.B.

453. Viscous properties of thixotropic materials. D. G. OSBORNE and S. THORNTON, *Brit. J. Appl. Phys.*, 1959, **10**, 214. University of Durham. Using a constant torque concentric cylinder viscometer, the viscous properties of thixotropic suspensions of nutile in oil were measured at various concentrations and temperatures. The shear stress is plotted against velocity gradient and is shown to have two components, one dependent, the other independent of temperature. The magnitude and speed of thixotropic change decreased with increase in shear stress and increased with increasing concentration. G.M.J.

454. Flow properties of distillates at low temperatures : A review. J. F. HUTTON, *J. Inst. Petrol*, 1959, **45**, 123–129. Shell Research Ltd. In this review the author first examines the standard test methods used in most investigations and then presents evidence to show that these methods are unreliable for comparison of flow properties. Following this the various theories of the mechanism of the formation and suppression of wax gel structures are discussed. A.D.B.

455. Movement of sand slurry through cracks. I. N. VASIL'EV, *Neftyanoe Khoz.*, 1958, **36**, 35. [Russian]

456. Deformation of gel cements during perforation. S. L. LANTSEVITSKAIA, A. K. NEVEROVA and IU. N. TER-GRIGORIAN, *Neftyanoe Khoz*, 1958, **36**, 26. [Russian]

457. A rheological approach to certain features of dense-medium coal-cleaning plant operation. G. F. EVESON, *J. Oil Col. Chem. Ass.*, 1959, **42**, 146, 179. Coal Treatment Laboratory, Mining Department, University of Birmingham. The salient features of dense-medium processes for coal cleaning are described and the importance of the rheological properties of the dense medium in governing the efficiency of the plant operation is outlined. A critical review is made of the techniques and viscometers which have been used in investigating the rheological properties of dense media and the validity of the conclusions drawn from these investigations is discussed. W.H.B.

458. Enthalpies of swelling of cation-exchange resins. D. DOLAR, M. MOCNIK and S. OMAN, *Vestn. Slovensk. Kem. Drustva*, 1958, **5**, 35–41.

459. Investigations on the visco-plastic properties of building materials. V. V. VASIL'EVA, *Kolloidnyi Zh.*, 1959, **21**, 151. Moscow Engineering Institute for Building Materials. The results are described of rheological studies on lime paste, lime-sand and lime-cement-sand mortars, with the aid of the Volarovich RV-4 viscometer. It was found that the yield value θ of the lime paste grows somewhat more rapidly with time than the visco-plasticity η_{pl}. The rheological characteristics of the lime-sand mortars (1 : 3, 1 : 4, 1 : 5) decrease in value with decreasing water content, but somewhat slower than the characteristic of lime paste. The parameters θ and η_{pl} of complex mortars (lime-cement-sand) are higher in value than those for lime paste and lime-sand mortars, owing to the presence of a second binder, cement, in the former. On increase in the water content of the complex mortars θ decreases more rapidly than η_{pl}. η_{pl} considerably increases with fall in temperature, whereas θ depends little on the latter. In this case the change in η_{pl} is determined mainly by changes in the viscosity of the dispersion medium, water, with temperature. As regards θ, it may to a certain extent be considered as similar to the friction of solids, which almost exhibits no change with temperature. The plasticity $\psi = \theta/\eta_{pl}$ of complex mortars increases with the temperature. [Russian] English abstract. Author

460. A numerical approach to the problem of sediment volume. M. J. VOLD, *J. Colloid Sci.*, 1959, **14**, 168–174. Department of Chemistry, University of Southern California, University Park, Los Angeles, California. The observed sediment volume of 3·5 cm^3/g for moist spheres in hydrocarbon liquids is shown to correspond exactly to a model in which each sphere coheres rigidly to the first sphere it contacts but is inconsistent with the existence of long range forces. R.B.B.

Section F

LIQUIDS

461. Fluid-flow in a well-bottom contact zone during hydraulic fracturing. IU. M. SHEKHTMAN, I. F. KURANOV and A. A. LARIN, *Neftyanoe Khoz.*, 1958, **36**, 40. [Russian]

462. Viscosity and density of typical oil-field waters in places of their occurrence. B. I. SERGEEVICH and T. P. ZHUZE, *Neftyanoe Khoz.*, 1958, **36**, 57. [Russian]

463. Viscosity of *n*-hexadecane. R. C. HARDY, *J. Res. Nat. Bur. Stand.*, 1958, **61**, 433–436. Attempts to assess the value of cetane and *n*-hexadecane, as calibration standards for viscometry showed them to be unsuitable because of the difficulty of purification. M.F.C.

464. Heat transfer in laminar flow through a tube. M. ABRAMOWITZ, W. F. CAHILL and C. WADE, *J. Res. Nat. Bur. Stand.*, 1959, **62**, 101–106. A parabolic distribution of velocity is assumed, and the effect of axial temperature changes are considered. M.F.C.

465. On the theory of flow of underground fluids in compressible strata. A. E. SCHEIDEGGER, *Canad. J. Phys.*, 1959, **37**, 276–284. Imperial Oil Research Laboratory, Calgary, Alberta. In general, the motion of the fluid cannot be separated from that of the medium. The problem of consolidation can be simplified in the case of underground fluids, since it can take place only in a vertical direction. Two cases have been considered : local isotropy, and local anisotropy, of stress and permeability. The basic differential flow equation for the two cases is deduced. M.F.C.

466. The stability of couette flow in an axial magnetic field. E. R. NIBLETT, *Canad. J. Phys.*, 1958, **36**, 1509–1525. Division of Geomagnetism, Dept. of Mines and Technical Surveys, Dominion Observatory, Ottawa. Chandrasekhar's theory of the stability of viscous flow of an electrically conducting liquid between coaxial rotating cylinders with perfectly conducting walls is extended to include the case of non-conducting walls, and it is found that their effect is to reduce the critical Taylor numbers and increase the wavelength of the instability patterns by considerable amounts. An experiment designed to measure the values of magnetic field and rotation speed at the onset of instability in mercury between Perspex cylinders is described. The radioactive isotopes Hg^{197} and Hg^{203} were used to trace the flow. The results support the theoretical prediction that the boundary conditions can have a large effect on the motion. Author

467. Cluster formation in relation to the viscosity of melts in the pre-freezing region. E. MCLAUGHLIN and A. R. UBBELOHDE, *Trans. Faraday Soc.*, 1958, **54**, 1804–1810. Dept. of Chemical Engineering, Imperial College of Science and Technology, London, S.W.7. As the freezing point is approached certain melts show an increase of viscosity considerably greater than the usual exponential temperature dependence. A model is proposed in which this feature is attributed to cluster formation. The model is tested for melts of *o*-terphenyl and indicates the presence of clusters of two or three molecules some 140 °C above the melting point, which pass into larger clusters to a marked extent some 25 °C above the freezing point. Comparison of the closely related triphenylene molecule shows much less cluster formation, as would be expected from the differences in structure of the two molecules. Further experimental values of the viscosity of *o*-terphenyl are reported. W.H.B.

468. Viscosity and self-diffusion in liquids. E. McLAUGHLIN, *Trans. Faraday Soc.*, 1959, **55**, 28–38. Dept. of Chemical Engineering, Imperial College, London. Coefficients of viscosity and self diffusion for some simple spherical and pseudo-spherically symmetric molecules are calculated from a rate theory of transport in systems involving holes, given only the molar volume of the liquid and the force constants of molecular interaction derived from the transport properties of the corresponding gases. Experiment and theory agree to within 10 per cent. W.H.B.

469. Entrainment in turbulent fluid jets. M. B. DONALD and H. SINGER, *Fluid Handling*, 1959, **111**, 102. Dept. of Chem. Engineering, University of London. The quantitative relations governing the entrainment of an enveloping liquid into a turbulent jet were investigated theoretically and experimentally. It was predicted and confirmed that the entrainment capacity and other kinetic parameters were functions of jet geometry only. The effects of fluid jet viscosity and Reynolds number were investigated using a gas (hydrogen) and liquids. The length of the potential core of the jet was determined with improved precision. (Report on paper presented to the Spring Meeting of the Institution of Chemical Engineers, 1959.) E.B.

470. The heat conductivity and viscosity of liquid helium—II. D. F. BREWER and D. O. EDWARDS, *Proc. Roy. Soc.*, 1959, **A251**, 247–264. The Clarendon Laboratory, University of Oxford.

471. Find blend viscosity by nomograph. D. S. DAVIS, *Petroleum Refin.*, 1959, **38**, 216. University of Alabama. Kendall and Monroe have shown that for a wide variety of binary mixtures, the cube roots of the viscosities are linear functions of the compositions. The author gives a nomograph to enable workers to determine a blend viscosity as rapidly as possible. A.D.B.

472. Some observations concerning the viscosity–temperature behaviour of hydrocarbons. W. C. WINNING, *J. Inst. Petrol.*, 1959, **45**, 9–15. Standard Oil Company (New Jersey). The viscosity temperature data given as the result of a literature search made by Grunberg and Nissan and also that provided by the report of A.P.I. research project No. 42 have been used to find empirical relationships for the viscosity/temperature characteristics of various families of hydrocarbons. The final equation which, it is claimed, holds good for all hydrocarbons, contains two parameters C and Q which depend on the particular hydrocarbon. The parameter Q is shown to depend on the hydrocarbon structure having a value of unity for all the normal paraffins. Q is increased by the presence of side chains and ring structures. A.D.B.

473. Rheological problems of lubrication. K. KIRSCHKE, *Chem.-Ing.-Tech.*, 1957, **29**, 746. Abstracted in *Lubric. Engng*, 1959, **15**, 71. The viscosities of mineral oils with and without addition of 3 to 15 per cent Oppanol B50 were measured in Umstatter's free flow and structural viscometers and in a 4-bearing lubricant tester. Although at small shear velocities the oils with additive have higher viscosities than the base oils,

they show smaller rotational moments, friction coefficients and heat production in the 4-bearing machine. The effective viscosities calculated from the three methods agree well. [Original in German] J.F.H.

474. The capillary rise of a liquid in a vertical strip of filter paper. T. GILLESPIE, *J. Colloid Sci.*, 1959, **14**, 123–130. Physical Research Laboratory, The Dow Chemical Company, Midland, Michigan. A theory previously developed by the author to describe the horizontal spreading of liquids in paper has been applied to the case of a liquid rising by capillary action in a vertical strip of filter paper. Surface roughness and time effects are taken into account. R.B.B.

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Section G

GENERAL

475. Sealing problems of high speed high altitude aircraft and guided missiles. E. G. ELLIS, *Sci. Lubric.*, 1959, **11**, 10–14. Summarizes the requirements for seals in hydraulic and propulsion systems. With reference to the literature, mention is made of the types of material now available, their properties and tests used in their evaluation. J.F.H.

476. Lubrication of artificial limbs. Anon, *Sci. Lubric.*, 1959, **11**, 23–24. Long abstracts are given of two papers presented at a symposium on biomechanics arranged by the Institution of Mechanical Engineers on 17 April 1959. In "The lubrication of animal joints", J. Charnley (Royal Infirmary, Manchester) gives reasons for the view that hydrodynamic lubrication does not occur in joints. Synovial fluid has no effect on coefficient of friction. PTFE is the best material for artificial joints. In "Some test on fluon as a material for artificial joints" by R. I. Tanner (University of Manchester), a test machine is described and experimental results are given. J.F.H.

477. Extrusion theory.—Parts I and II. D. M. HULBERT, S. KATZ and L. F. STREET, *Plastics Tech.*, 1958, 1110; 1959, 39. Stamford Laboratories, American Cyanamid Co., Stamford, Conn. A descriptive and largely non-mathematical treatment of the behaviour of fluids under the action of a rotating extruder screw in a stationary barrel. The effects of rheological properties of the fluid are not considered. E.B.

478. Estimate gas or liquid viscosity data. CHEN-JUNG HUANG and A. I. JOHNSON, *Petrol Refin.*, 1959, **38**, 217–226. University of Houston. A review of the empirical methods available for estimating the viscosity of liquids and gases is given. This includes the effects of temperature and structure in the case of vapours and liquids. The viscosity of mixtures of vapours is also dealt with. A.D.B.

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Kolloidzschr.
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LIST OF JOURNALS COVERED FOR RHEOLOGY ABSTRACTS

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PROGRESS IN NUCLEAR ENERGY, Series V, Volume 3

METALLURGY AND FUELS

Editors

H. M. FINNISTON *and* **J. P. HOWE**

This is the fifth in a series of eleven, being the edited proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy held at Geneva. Between them they cover the entire field of progress in nuclear energy. The other volumes are PHYSICS AND MATHEMATICS, REACTORS, PROCESS CHEMISTRY, TECHNOLOGY AND ENGINEERING, BIOLOGICAL SCIENCES, MEDICAL SCIENCES, ECONOMICS, ANALYTICAL CHEMISTRY, PLASMA PHYSICS AND THERMONUCLEAR RESEARCH and HEALTH PHYSICS.

This volume gives a comprehensive review of basic metallurgy and the technology of metals specific to atomic energy, with particular emphasis on advances in solid state studies. The work is divided into two sections—the first dealing with the metallurgical development of such reactor fuels as uranium, thorium zirconium and beryllium ; the other section deals with the processes of atomic energy with reference to service control and technology, discussing kinetics of transformations of uranium alloys, radiation effects of high energy electrons in metals, neutron irradiation on crystalline and glassy inorganic solids and thorium alloy systems.

This report from many countries on developing fuels for a diverse range of reactor systems will be invaluable to all metallurgists in the atomic energy field.

Some of the papers and authors are:

Advances in the Physical Metallurgy of Uranium and its Alloys—**H. H. Chiswik**

Irradiation Induced Phase Changes in Uranium Base Alloys—**M. L. Bleiberg**

The Corrosion of Plutonium and Uranium—**J. T. Waber**

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Section A

THEORETICAL

479. Flow of an incompressible visco-plastic layer on an inclined plane. P. R. PASLAY and A. SLIBAR, *Trans. Soc. Rheol.*, 1958, **2**, 255–262. General Electric Co., Schenectady, New York. The complete solution, stresses and velocities, of the flow of a Bingham plastic on an infinite flat plate due to gravity forces is given. This solution has practical application in emulsion coating and paint technology. Selection of appropriate material constants for incipient flow from experimental data is discussed in the Appendix. Author

480. Folding of a layered viscoelastic medium derived from an exact stability theory of a continuum under initial stress. M. A. BIOT, *Quart. Appl. Math.*, 1959, **17**, 185–204. Shell Development Company, New York.

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481. General solution of Reynolds equation for a journal bearing of finite width. L. N. TAO, *Quart. Appl. Math.*, 1959, **17**, 129–136. Illinois Institute of Technology. The Reynolds equation, by a suitable transformation of variables, is changed to a comparatively unknown equation, Heun's equation. The convergency of the Heun function is studied. The pressure distributions as well as the eigenvalues and their eigenfunctions are established, and finally the load carrying capacity and the coefficient of friction of the bearing are determined. Author

482. Film and substrate flow in surface channels. R. S. HANSEN, *J. Phys. Chem.*, 1959, **63**, 637. Institute for Atomic Research and Department of Chemistry, Iowa State College, Ames, Iowa, U.S.A. A short theoretical note on the transfer of monolayers in surface channels. D.W.S.

483. On the foundations of linear isotropic visco-elasticity. D. R. BLAND, *Proc. Roy. Soc.*, 1959, **A250**, 524–549. Department of Mathematics, University of Manchester. The properties of a linear visco-elastic material are developed from the hypothesis that the microscopic structure of such a material is mechanically equivalent to a network of elastic and viscous elements. Author

484. Theories of streaming double refraction. H. G. JERRARD, *Chem. Rev.*, 1959, **59**, 345–428. Dept. of Physics, University of Southampton, Southampton. In this detailed review (171 references), the early theories are outlined, while more recent ones are discussed under three headings : theories for rigid particles, theories for liquids and theories for flexible particles. The review concludes with critical comments on these theories. W.G.C.

485. A modification of Prager's hardening rule. H. ZIEGLER, *Quart. Appl. Math.*, 1959, **17**, 55–65. Eidgenössische Technische Hochschule, Zurich.

486. Plastic disturbances whose speed of propagation is less than the velocity of a sound wave. T. Y. THOMAS, *J. Math. Mech.*, 1958, **7**, 893–900. Graduate Institute for Mathematics and Mechanics, Bloomington, Indiana.

487. Rupture of round bars by tension. T. Y. THOMAS, *J. Math. Mech.*, 1959, **8**, 1–25. Graduate Institute for Mathematics and Mechanics, Bloomington, Indiana.

488. The derivation of stress–deformation relations for a Stokesian fluid. J. SERRIN, *J. Math. Mech.*, 1959, **8**, 459–469. University of Minnesota, Minneapolis, Minnesota. The purpose of this paper is to give a simple and complete treatment of the constitutive equation when the stress tensor is a function of the deformation tensor (Stokesian fluid).
Author

489. Propagation of elastic wave motion from an impulse source along a fluid/solid interface—I. Experimental pressure response.—II. Theoretical pressure response.—III. The pseudo-Rayleigh wave. W. L. ROEVER, E. STRICK and T. F. VINING, *Phil. Trans.*, 1959, **A251**, 455–523. Shell Development Company, Exploration and Production Research Division, Houston, Texas.

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Section B

INSTRUMENTS AND TECHNIQUES

490. Theoretical evaluation of capillary viscometers for the measurement of the viscosity of suspensions of spheres. A. D. MAUDE, *Brit. J. Appl. Phys.*, 1959, **10**, 371. Liverpool College of Technology. The effect of a suspension of spheres in a Newtonian fluid on its viscosity measured in a capillary viscometer is compared theoretically with that in an idealized viscometer. The effect of the velocity profile and of mechanical interaction within the tube wall on the perturbation velocity fields are considered. This theory is compared with published data whence it is indicated that some previously unconsidered factor must be operating.
G.M.J.

491. The capillary experiment in rheology. W. PHILIPPOFF and F. H. GASKINS, *Trans. Soc. Rheol.*, 1958, **2**, 263–284. The Franklin Institute, Laboratories for Research and Development, Philadelphia 3, Pennsylvania. In previous publications we have shown that the potential energy in flow can be calculated from the applied shear stress r and the " recoverable shear " s. Here the concept of a potential elastic energy existing in a liquid emerging from a capillary gives a means of determining s from the predicted and experimentally-found linear relationship between r and the L/R ratio. With poly*iso*butylene solutions the calculated recoverable shears correlate satisfactorily with the measurements previously reported. This condition of potential energy in flow has also been noted with molten polyethylene and solutions of aluminium dilaurate.
Author

492. Determining viscosity of melted high polymers with the aid of a supersonic device. M. CHATAIN, G. HERY and J. PREUAT, *Industr. Plast. Mod.*, 1958, **10**, 32. The design and principle of the Rich–Roth Ultraviscoson are described. The method of operation and results on different plastics are discussed. (Abstract from *Plastics Tech.*, 1959, **5**, 98.) [French]

493. A torsion pendulum for dynamic and creep measurements of soft viscoelastic materials. D. J. PLAZEK, M. N. VRANCKEN and J. W. BERGE, *Trans. Soc. Rheol.*, 1958, **2**, 39–51. University of Wisconsin, Madison, Wisconsin. An instrument designed to measure the mechanical properties of soft viscoelastic materials with low loss has been built and tested. It is used as a free vibration torsion pendulum for obtaining low frequency dynamic mechanical properties (0·02 to 10 c/s) and as a torsional creep apparatus capable of measurements involving low stresses (e.g. 100 dynes/cm²). Since the discshaped samples are held between two parallel surfaces by means of a normal force, measurements can be made on materials whose consistencies defy clamping. The maximum angular deformation of the sample can be varied from 0·5 to 1·5°. The accessible temperature range is −45 to 160°C. Detection of the motion is accomplished with a reflected light beam, a barrier-type photocell and a Sanborn chart recorder. Dynamic measurements made on the widely studied National Bureau of Standards poly*iso*butylene sample compared favourably with previous measurements from this laboratory and elsewhere. Similar experiments on a 10% gel of polyvinyl chloride in dimethylthianthrene showed that storage moduli as low as 10^5 dyne/cm² and loss tangents as low as 0·07 could be satisfactorily measured. Author

494. A new apparatus (the elasto-relaxometer) for studying large reversible deformations, "toughness" and relaxation of high-elastic colloidal systems and polymer solutions. A. A. TRAPEZNIKOV, *Kolloidnyi Zh.*, 1959, **21**, 108. Laboratory of Oleocolloids and Monolayers, Institute of Physiological Chemistry, Academy of Sciences of the U.S.S.R., Moscow. Describes in detail construction of concentric cylinder apparatus. Studies gels of aluminium naphthenate in decalin.
G.W.S.B.

495. A modified vicat-type apparatus for measuring the softening point of thermoplastic plastics and laminates. G. F. L. EHLERS, *A.S.T.M. Bull.*, 1959, No. 236, 54. A modified apparatus is described that provides better heat transfer than the original apparatus, with temperature measurements made directly on the specimen. (Abstract from *Plastics Tech.*, 1959, **5**, 96.)

496. Review of dynamical testing methods for high polymer solids—VI. Torsion. F. WINKLER, *Faserforschung*, 1959, **8**, 376–379. Inst. Faserstoff-Forschung, Teltow-Seehof. A continuation, with 47 references, of earlier brief reviews. [German]

Section C

METALS AND OTHER SOLIDS

497. The creep of snow under combined stress. J. K. LANDAUER, *Trans. Soc. Rheol.*, 1958, **2**, 175–194. U.S. Army Snow, Ice, and Permafrost Research Establishment, Wilmette, Illinois. Experiments have been

performed on the creep of sifted snows under uniaxial, hydrostatic and confined-side compressive stresses. The dependence of creep rate on stress (in the range 4 to 40 lb/cm^2), time (up to several thousand seconds), temperature (between $-3{\cdot}6$ and $-13{\cdot}6$°C) and density (from $0{\cdot}36$ to $0{\cdot}63$ g/cm^3) was investigated. For one group of tests, stress was applied for constant time increments, while for another group, stress was continued until an arbitrarily selected small change in density was reached. The results are discussed on the basis of an additive theory for combined stresses. Author

498. Surface cracks on glass. A. S. ARGON, *Proc. Roy. Soc.*, 1959, **A250**, 472–481. Massachusetts Institute of Technology, Cambridge, Massachusetts. The sodium vapour etching experiments of Andrade and Tsien (*Proc. Roy. Soc.*, 1937, **A159**, 346) were repeated with chemical Pyrex glass. With the aid of a ball indenter it was possible to determine the real nature of the surface cracks that were developed. Author

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499. Distribution of cracks on glass surfaces. A. S. ARGON, *Proc. Roy. Soc.*, 1959, **A250**, 482–492. Massachusetts Institute of Technology, Cambridge, Massachusetts. The density distributions of surface cracks of various severities is calculated for a chemical Pyrex glass and for a window glass. Author

500. The structure and structural-mechanical properties of inorganic glasses. G. M. BARTENEV and S. A. EREMEEVA, *Kolloidnyi Zh.*, 1959, **21**, 249. State Institute for Scientific Investigation of Glass, Moscow. Glasses are treated as intermediate between thixotropic colloidal systems and high-polymers. A network chain structure is postulated for the higher temperature range. Since the yield-value is low, glass in this range behaves as a viscous fluid to all but the smallest stresses, to which it is elastic. [Russian] English abstract. G.W.S.B.

501. Variation of the viscosity of glass as a function of the temperature. M. PROD'HOMME, *C. R. Acad. Sci., Paris*, 1959, **248**, 1325–1328. [French]

502. Determination of elastic moduli of sintered metal powder compacts using an ultrasonic method. P. RAMA RAO and A. A. KRISHNAN, *J. Sci. Industr. Res.*, 1959, **18B**, 260–261. Department of Metallurgy, Indian Institute of Science, Bangalore. In this brief note, Young's and rigidity moduli are given for sintered and compacted aluminium, bismuth, brass (60–40), copper and tin, in comparison with literature data for the cast material. W.G.C.

503. Compaction of briquettes. H. R. GREGORY, D. C. RHYS JONES and J. W. PHILLIPS, *Nature, Lond.*, 1959, **184**, 120–121. National Coal Board, Coal Research Establishment, Stoke Orchard, Cheltenham, Glos. Between, but not including, the extremes of graphite powder and anthracite powder, the strength and density of coal powder briquettes formed by compression in a die may be substantially increased by applying extra shear strain. W.G.C.

Section D

POLYMERS, ELASTOMERS AND VISCOELASTIC MATERIALS

504. Time dependence of mechanical breakdown in bundles of fibres—III. The power law breakdown rule. B. D. COLEMAN, *Trans. Soc. Rheol.*, 1958, **2**, 195–218. Mellon Institute, Pittsburgh 13, Pennsylvania. The problem of calculating relationships between the strength of a bundle and the strength of its constitutent filaments is discussed. Detailed calculations are done for the case in which the filaments are drawn from a first-order ensemble with the special property that the average lifetime of the filaments, when tested separately under static loads, varies as a power of the applied stress. For this special case it is possible to derive some general results which are valid whatever the time dependence of the total load. The distribution functions for the lifetime of ideal bundles are calculated for both small and large bundles subjected to arbitrary loading histories. The conditions under which the strength of a bundle decreases with increasing number of filaments are examined. Author

505. The comparison of time dependent mechanical properties of plastics. B. MAXWELL, *S.P.E.J.*, 1959, **15**, 480. Princeton University Plastics Laboratory. Creep and stress relaxation are defined and the use of dynamic measurements to study these time dependent properties is discussed. Three dimensional diagrams, showing the effects of temperature and frequency on modulus and loss factor, are given for polymethyl methacrylate and polyethylene and the effects of adding various amounts of plasticizer (TCP) to PVC are shown. E.B.

506. Approximate equations for interconverting the various mechanical properties of linear viscoelastic materials. T. L. SMITH, *Trans. Soc. Rheol.*, 1958, **2**, 131–151. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California. Approximate equations are given for interconverting the storage modulus G', the loss modulus G'', and the stress relaxation modulus $G(t)$ by using the relaxation spectrum H, and similarly for interconverting the storage compliance J', the loss compliance J'', and the creep compliance $J(t)$ by using the retardation spectrum L. Approximations to the exact equations of Gross are also given for interconverting H and L. All approximate equations are based on the assumption that $H=kr^m$ and $L=gr^n$ over a relatively narrow region of the time-scale. To indicate the accuracy of the approximate equations, calculations were made using published data on the NBS poly*iso*butylene. Author

507. On relaxation spectra in high polymers. B. ALBRECHT and A. M. FREUDENTHAL, *Trans. Soc. Rheol.*, 1958, **2**, 95–130. Columbia University, New York, N.Y. The spectrum of relaxation times has been constructed for a fabric-filled phenolic of commercial type by combining the results of torsion tests on cylindrical specimens over a relatively wide range of strain rates and temperatures. The resulting spectrum is not unimodal and extends over almost sixty orders of magnitude ; thus the mechanical response of high polymers at a certain combination of strain rate and temperature can be determined only by tests at this same combination. Prediction of such performance requires a knowledge of the spectrum over its entire range. Author

508. Anisotropic light scattering by flowing flexible macromolecules. M. NAKAGAKI and W. HELLER, *J. Polym. Sci.*, 1959, **38**, 117–131. Chemistry Dept., Wayne State University, Detroit, Michigan. The anisotropic light scattering to be expected from flexible macromolecules deformed in laminar flow is calculated. The model used assumes that the deformed molecule can be represented by a statistical spheroid. The results predict that the anisotropic scattering will give quantitative knowledge of either the shape or the degree of swelling of a flexible molecule depending on which of these is already known. E.H.A.

509. The infrared streaming dichroism of some synthetic polypeptides. G. R. BIRD and E. R. BLOUT, *J. Amer. Chem. Soc.*, 1959, **81**, 2499, 2503. Children's Cancer Research Foundation and Chemical Research Laboratory of Polaroid Corpn., Boston 15, and Cambridge, 39, Mass. Observations on the infra-red streaming dichroism and viscosity data are obtained for aqueous solutions of poly-γ-benzyl-L-glutamate, poly-L-glutamic acid, poly-L-carbobenzyloxy-L-lysine and 7 : 3 copoly-L-glutamic acid : L-lysine hydrobromide. W.H.B.

510. Structure–property relationships in synthetic fibres—Part I. Structure as revealed by sonic observations. W. H. CHARCH and W. W. MOSELEY, Jr., *Text. Res. J.*, 1959, **29**, 525. Pioneering Research Division, Textile Fibers Dept. E. I. du Pont de Nemours and Co., Inc., Wilmington, Del., U.S.A. The velocity of 10 kc/s sound waves has been measured in a range of synthetic fibres at various temperatures and draw ratios. A.K.

511. Bulk viscosity of polymeric systems. N. HIRAI and H. EYRING, *J. Polym. Sci.*, 1959, **37**, 51–70. Dept. of Chemistry, University of Utah, Salt Lake City, Utah, U.S.A. The theory of bulk viscosity as developed for the liquid state was applied to amorphous high polymeric systems. The isothermal volume contraction, the dependence of shear viscosity and the fictive temperature of quenched high polymeric substances are all related to the bulk viscosity and explained by this theory. Simple representations are given for compressibility, bulk modulus, shear modulus, thermal expansion coefficient and heat capacity, all of which are necessary to discuss the bulk viscosity. The theory has been compared with the experimental results for natural rubber, polystyrene, poly*iso*butylene and polyester. Author

512. Dynamics of branched polymer molecules in dilute solution. B. H. ZIMM and R. W. KILB, *J. Polym. Sci.*, 1959, **37**, 19–42. General Electric Research Laboratory, Schenectady, New York, U.S.A. Theoretical formulae for the intrinsic viscosity and visco-elastic properties of some model branched molecules in solution are calculated by means of the normal co-ordinate method of Rouse modified to include hydrodynamic interactions. The ratio of the intrinsic viscosity of a branched molecule to that of a linear molecule of equal weight is found to vary almost as the square root of the ratio of the mean square radii and not as the three-halves power as previously postulated. Several sets of experimental data in the literature are shown to agree well with this hypothesis. Author

513. Study of entanglement of polymers in solution by viscosity measurements. S. H. MARON, N. NAKAJIMA and I. M. KRIEGER, *J. Polym. Sci.*, 1959, **37**, 1–18. Physical Chemistry Laboratory, Dept. of Chemistry and Chemical Engineering, Case Institute of Technology, Cleveland, Ohio, U.S.A. A study was made of the flow behaviour of solutions of polystyrene in different solvents in both the Newtonian and non-Newtonian regions. By application of the Ree–Eyring theory the experimental data may be represented in terms of two flow units and the effective hydrodynamic volume occupied per unit volume of the polymer deduced. The variation of this volume factor with temperature, solvent and concentration is discussed. In the state of tightest molecular coiling the polymer molecule occupies a volume two to three times that for the bulk polymer. E.H.A.

514. A viscometric criterion of polymer polydispersity. H. L. FRISCH and J. L. LUNDBERG, *J. Polym. Sci.*, 1959, **37**, 123–129. Bell Telephone Laboratories Inc., Murray Hill, New Jersey, U.S.A. An index of the molecular weight polydispersity of a polymer is given by the ratio of the viscosity-average molecular weight in two different solvents and is proportional to the weight-to-number-average molecular weight ratio. Though experimentally simple the method lacks the reliability of more conventional measurements of polydispersity. The possible use of multiple solvents for more complete characterization of the molecular weight distribution is discussed. E.H.A.

515. The radiation-induced polymerization of *iso*butene. W. H. T. DAWSON, S. H. PINNER and R. WORRALL, *Proc. Roy. Soc.*, 1959, **A252**, 187–196. Tube Investments Research Laboratories, Cambridge, England.

516. Mechanical properties of acrylonitrile polymers. R. STEFANI, M. CHEVRETON, J. TERRIER and C. EYRAUD, *C. R. Acad. Sci., Paris*, 1959, **248**, 2006–2008. [French]

517. Rheology of polystyrene in dilute solutions—Part I. Effect of the flow properties on the viscosity limit. G. M. GUZMAN and J. M. G. FATOU, *An. Soc. Esp. Fis. Quim.*, 1959, **55B**, 31–42. [Spanish] English summary.

518. Rheology of polystyrene in dilute solutions—Part 2. Flow behaviour of several fractions. G. M. GUZMAN and L. ALONSO, *An. Soc. Esp. Fis. Quim.*, 1959, **55B**, 43–52. [Spanish] English summary.

519. Viscosity of ternary solutions : poly(vinyl alcohol)–water–mineral salt. H. BUC, *C. R. Acad. Sci., Paris*, 1959, **248**, 1335–1337. [French]

520. Strain-induced crystallization in polyethylene terephthalate. (Note.) A. B. THOMPSON, *J. Polym. Sci.*, 1959, **37**, 313–315. Research Dept., I.C.I. Fibres Division, Harrogate, Yorks. The inadequacy of Maxwell's viscoelastic equation in representing the behaviour of a polymeric material is demonstrated, and a modified form of the equation is proposed. The effects of introducing the new equation into the author's theory of strain-induced crystallization in polymers are briefly discussed. E.H.A.

521. Percussion deformation of rubber. G. M. BARTENEV and N. M. NOVIKOVA, *Kolloidnyi Zh.*, 1959, **21**, 3. Institute for Scientific Investigations for the Synthetic Rubber Industry, Moscow. A method has been proposed for determining the percussion modulus of rubber on compression. It has been shown that there is a linear relationship between the kinetic energy and the square of the percussion deformation and it has been suggested that the coefficient of proportionality between the two quantities be called the percussion modulus. The correlation also holds for low temperatures, so that one can estimate the frost stability of rubbers to percussion deformation by the sharp change in the percussion modulus. [Russian] English abstract. Authors

522. Lignin as a reinforcing agent for rubber SKS-30. YU. F. KURDUBOV, A. P. PISARENKO, C. I. RUBINA and B. V. SHTARKH. *Kolloidnyi Zh.*, 1959, **21**, 306. Institute for Scientific Studies of Filamentous Materials and Tanning Techniques, Moscow. [Russian] English abstract. G.W.S.B.

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523. The influence of the viscosity of rubber latex on the gelatinization rate. D. M. SANDOMIRSKII and M. K. VDOVCHENKOVA, *Kolloidnyi Zh.*, 1959, **21**, 132 (letter). Institute for Scientific Studies in Synthetic Rubber and Latex Wares, Moscow. The rate of gelation of latex depends not only upon the number of destabilizing ions formed but also upon the rate of their diffusion determined by the viscosity of the medium. [Russian] English abstract. Authors

524. The tensile strength of GR-S elastomers. L. M. EPSTEIN and R. P. SMITH, *Trans. Soc. Rheol.*, 1958, **2**, 219–238. Mellon Institute, Pittsburgh 13, Pennsylvania. Specimens of purified GR-S were cross-linked with from 0·2 to 4·0 per cent decamethylenebismethylazodicarboxylate. The network activity (i.e. number of stress-bearing chains per cubic centimetre) calculated from the quantity of cross-linking agent and polymer molecular weight was somewhat lower than that determined by swelling and equilibrium tension measurements, especially at low degrees of cross-linking. Ultimate strength and elongation were measured at extension rates of 2 and 20 in/min. These were also measured at 2 in/min on sets of specimens which were swollen with 70 per cent by volume of mineral oil, sets from which the soluble polymer was extracted, and sets from which the soluble polymer was extracted and replaced with an equal volume of mineral oil. Attempts were made to interpret the results according to theories previously proposed for amorphous cross-linked elastomers. It was observed that despite wide differences in tensile strength among the sets which received the various treatments noted above, the ultimate elongation varied relatively little. A theory for the ultimate elongation is proposed which is in good agreement with the data. It is based on the assumption that a specimen breaks when the number of broken chains per unit volume reaches a critical value. The broken chains are those which in the undeformed network have end-to-end distances closest to their contour lengths. Authors

525. The tensile strength of textile fibres at different elongation speeds. H. MARTIN, *Faserforschung*, 1959, **8**, 371–376. Inst. Technologie der Fasern, Dresden. The elongation and tension at break of various natural

and synthetic textile fibres are measured for rates of elongation in the range 0·04 to 1600 per cent/sec. [German] A.S.L.

526. Dynamic mechanical properties of fluorochemical elastomers. K. E. OWENS and C. A. DAHLQUIST, *Trans. Soc. Rheol.*, 1958, **2**, 23–38. Minnesota Mining and Manufacturing Co., St. Paul, Minnesota. The dynamic mechanical properties of three fluorinated elastomers were determined by use of the double transducer of Fitzgerald and Ferry. The measurements cover a temperature range of −40 to 100°C and a frequency range of 24 to 5200 c/s. The elastomers studied are the acrylic 3M Brand Fluororubber 1F4, a homopolymer of 3-trifluoromethoxy-1, 1-dihydroperfluoropropyl acrylate, and Dow Corning Silastic Rubber LS-53. Master dispersion curves of the compliances at 25°C vs. time have been obtained using the reduced variables treatment of Ferry. The position in the time scale and extent of the dispersion regions are discussed. The apparent heats of activation per chain segment and relaxation distribution functions were determined and are discussed in reference to the reported values for poly*iso*butylene. The universal function for the temperature dependence of mechanical relaxations in amorphous polymers applies to these fluorinated elastomers. Author

527. Viscoelastic behaviour of monolayers of serum albumin and (bovine) γ-globulin. J. LLOPIS and A. ALBERT, *An. Soc. Esp. Fis. Quim.*, 1959, **55B**, 109–118. [Spanish] English summary.

528. On interactions of proteins—XIII. Heat denaturation of human serum albumin in sodium chloride solutions. P. MUNK, B. SEDLACEK and S. STOKROVA, *Coll. Trav. Chim. Tchécosl.*, 1959, **24**, 2247–2265. Chem. Inst., Tschecho. Akad. der Wiss., Prague. The changes with time of the size, shape, and weight of the albumin particles are investigated by means of viscosity and light scattering measurements, and indicate that the denatured albumin consists of many different types of particle. [German] A.S.L.

Section E

PASTES AND SUSPENSIONS

529. Flow behaviour of concentrated (dilatant) suspensions. A. B. METZNER and M. WHITLOCK, *Trans. Soc. Rheol.*, 1958, **2**, 239–254. University of Delaware, Newark, Delaware. The purpose of this work was to study the factors influencing the flow behaviour of concentrated suspensions; particular emphasis was placed on study of the factors which determine the conditions under which dilatancy may occur. The most important variables studied were solids concentration and viscosity of the suspending medium. It was found that the frequently quoted observation that dilatant non-Newtonian behaviour occurs when a suspension has dilated volumetrically sufficiently to appear to be dry visually is not quantitatively correct. Instead, visual dryness was found to occur at shear stresses well below those at which rheological dilatancy, as determined by inspection of the flow curve, occurred. Rheological dilatancy was found to increase with increasing shear stresses only a few fold higher than those at which dilatancy first occurred the suspension was found to fracture. Author

530. Studies of the viscosity and sedimentation of suspensions—Part 5. The viscosity of settling suspensions of spherical particles. D. R. OLIVER and S. G. WARD. *Brit. J. Appl. Phys.*, 1959, **10**, 317. Birmingham University, England. The viscosities of settling suspensions of spherical particles were measured using an efflux capillary-tube viscometer. The viscosities were compared with those of stable suspensions whence it was found that the degree of instability affects the viscosity–concentration relationships. Measured viscosity values are modified by a wall effect which changes with the volume concentration of solids and the degree of instability. The connected viscosities are related to the volume concentration by a single type of equation akin to that for stable suspensions.

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531. The dynamic mechanical properties of a model filled system : poly*iso*butylene–glass beads. R. F. LANDEL, *Trans. Soc. Rheol.*, 1958, **2**, 53–75. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California. The dynamic mechanical properties of three dispersions of 40 μ diameter glass beads in NBS poly*iso*butylene were studied in the rubber-to-glass transition zone. These dispersions contained 8·7, 20·3 and 36·7 per cent beads by volume. The real and imaginary components of the complex shear compliances were measured in a Fitzgerald transducer apparatus at frequencies between 24 and 600 c/s and at temperatures between −45 and 70°C. The temperature shift factors required to superpose the compliance data for the three dispersions are nearly identical to those for unfilled poly*iso*butylene. The reinforcement in the long-time end of the transition zone is predicted by the Guth–Smallwood equation :

$$M = M_0(1 + 2{\cdot}5\phi + 14{\cdot}1\phi^2)$$

where M_0 is the modulus of the unfilled polymer and ϕ is the volume concentration of the filler. However the filler broadens the dispersion curves, and consequently the equation does not hold at shorter times. Certain similarities between the properties of the dispersions and those of crystalline polymers are described. Author

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D.W.S.

533. Influence of an ultrasonic high frequency field on plastic pastes. M. N. GOL'DSHTEIN and E. M. GUTMAN, *Kolloidnyi Zh.*, 1959, **21**, 272. Dnepropetrovskii Institute of Transport Engineering. The dilatancy of loaded clay pastes under the action of ultrasonics depends on their hydrophil characteristics and degree of dispersion. The greatest effects are found with Na montmorillonites. [Russian] English abstract.

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534. The preparation of finely dispersed fractions of Askangel and the investigation of their thixotropic properties. M. E. SHISHNIASHVILI and A. L. AVSARKISOVA. *Kolloidnyi Zh.*, 1959, **21**, 364. Laboratory of Colloid Chemistry, Institute of Chemistry of Georgia S.S.R., Tbilisi. [Russian] English abstract. G.W.S.B.

535. Solution viscosity behaviour of some metal Schiff base chelates. ROBERT G. CHARLES, *J. Amer. Chem. Soc.*, 1959, **81**, 1793, 1795. Westinghouse Research Laboratories, Pittsburgh 35, Pa. Viscosity measurements are suggested as useful adjuncts to other physical methods for the study of metal chelate compounds dissolved in organic solvents. In favourable instances such measurements can give information relative to the steric configuration of the dissolved molecules and to the degree and type of interaction of the solute molecules with the solvent. The viscosities of dilute solutions derived from the members of three homologous series Cu(II), Ni(II) and Zn(II)N-(*n*-alkyl)-salicylaldimine chelates have been studied, using as solvents toluene, dioxane and pyridine. W.H.B.

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538. Studies in the field of the physico-chemistry of agar—3. On factors determining the visco-elastic properties of agar gels. S. A. GLIKMAN and I. G. SHUBTSOVA, *Kolloidnyi Zh.*, 1959, **21**, 25. Chernishevskii State University of Saratov. The data are classified according to a four-parameter model (Burgers), loading and recovery curves being analysed for a series of stresses. Gels are prepared by successive extraction at increasing temperatures. The Burgers parameters increase with increasing $[\eta]$, decreasing SO_4 content and increasing Ca/SO_4 ratio. Main factor defining visco-elastic properties is degree of polymerization. [Russian] English abstract. G.W.S.B.

539. Mechanical behaviour of hydrogels of agar-agar. K. ARAKAWA and K. ATSUMI, *J. Chem. Soc. Japan*, 1959, **80**, 133–135. [Japanese] English summary.

540. Viscosity of aqueous solutions of mercury (II) chloride. S. ALAMELU and C. V. SURYANARAYANA, *Mh. Chem.*, 1959, **90**, 36–40. [German]

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542. Physical changes in milk caused by the action of rennet—V. Effects of varying concentrations of milk powder and of low temperature treatment. G. W. SCOTT BLAIR and J. BURNETT, *J. Dairy Res.*, 1959, **26**, 144. National Institute for Research in Dairying, Reading. The Burgers parameters of milk gel increase with increasing concentration following a power law. The intercepts of the setting curves decrease almost linearly with concentration. The slopes and intercepts of these curves represent independent properties of the samples. The milk is fat-free and, since lactose has little effect, the behaviour is mainly concerned with casein concentration. The effects of allowing the earlier stages of rennet action, which do not cause gelation, to take place in the cold are discussed. The results are not consistent with any simple theory of the action of the enzyme.

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Section F

LIQUIDS

543. Rheology of peeling in a Newtonian liquid. J. J. BIKERMAN and W. YAP, *Trans. Soc. Rheol.*, 1958, **2**, 9–21. Dept. of Civil Engineering, Massachusetts Institute of Technology, Cambridge, 39, Mass. A metal ribbon was pressed against a rigid plate, the space between the plate and the ribbon being filled with a viscous liquid (two hydrocarbon oils and chlorinated paraffin oil were used). Then the ribbon was peeled off, and time t_m of separation measured as a function of the applied load W. An approximate rheological theory of the function $E_m = f(W)$ was developed, analogous to Stefan's theory for tensile separation. The equations derived were in satisfactory agreement with experiment as far as the modulus of elasticity of the ribbons (aluminium, copper, and steel foils) and the viscosity of the liquids were concerned. Thus, tackiness measured by peeling, similarly to tackiness measured by tensile pull, has no connexion with the theoretical forces of adhesion.

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544. The stability of a viscous liquid in a vertical tube containing porous material. R. A. WOODING, *Proc. Roy. Soc.*, 1959, **A252**, 120–134. Emmanuel College, University of Cambridge.

Section G

GENERAL

545. Performance of pressure sensitive materials. H. J. BOMELBURG, *Rev. Sci. Instrum.*, 1959, **30**, 43–44. Ballistics Research Laboratories, Maryland. Ten available pressure cells of different shape and size containing rare earths treated with zirconium tetrachloride, and laboratory made cells, have been examined by determining the pressure response of electrical resistance. In all cases a continuous increase of pressure showed decrease of resistance, but with discontinuities, sensitivity to vibration, and also a drift of readings.

546. Flow through capillary tubing with eccentric annular sections. C. H. BACHMAN and H. G. HOTTENROTT, *Rev. Sci. Instrum.*, 1959, **30**, 126–131. Department of Physics, Syracuse University, Syracuse 10, New York. Gas flow through capillaries obstructed by wire inserts was investigated for ratios of core to capillary diameters of 0·08 to 0·9. Deviations from Poiseuille flow are presented in a curve which gives flow rates correct to from 5 to 10 per cent.

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Bitumen, Teere, Asphalte u. Peche
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Brit. Plast.
Brot. u. Gebäck.
Bull. Acad. Sci. U.R.S.S.
Bull. Amer. Ceram. Soc.

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J. Text. Inst.

Kolloidnyĭ Zh.
Kolloidzschr.
Kunststoffe

Lab. Practice
Lubric. Engng.

Mod. Plast.

Nature, Lond.
Neftyanoe Khoz.
NLGI Spokesman
Nuovo Cim.

Oil Ind., Moscow

Paint J. Aust. N.Z.
Paint Manuf.
Paint Tech.
Petrol Engr.
Petrol Process.
Petrol Refin.
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Rev. Sci. Instrum.
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Rubb. Chem. Technol.

Sci. Lubric.
Silicates Industr.
Soil Sci.
Sov. Phys. JETP
S.P.E.J.
Svensk Pappers Tidning

Tappi

Text. Res. J.
Trans. Brit. Ceram. Soc.
Trans. Faraday Soc.
Trans. Plast. Inst., Lond.
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Verres et Réfr.

Wear
Wire Ind.
Wire Prodn.
Wire and Wire Prodn.

Zement-Kalk-Gips

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Summaries of papers read at the joint Autumn Meeting of the British Society of Rheology and the Acoustics Group of the Physical Society.

Monday, 14 *September—Dynamical Flow Properties of Liquids*

Measurements of Shear Elasticity and Viscosity of Polymer Liquids and Solutions which show Violations of the Tobolsky–Leaderman–Ferry Reduction Formula at High Frequency

By W. P. Mason

A number of low and high frequency instruments have been devised for measuring the shear properties of polymer solutions, liquids and solids. On account of the high attenuation of shear waves in these liquids and solids, all of them depend on measuring the characteristic impedance of the substance which can be related to the inherent shear stiffness and viscosity of the material. In the low frequency range the instruments most widely used are the Fitzgerald and Ferry transducer, the tuning fork of Mason and the torsional pendulum of Sittel, Rouse and Bailey. In the medium frequency range, the torsional crystal method of Mason and the travelling torsional wave system of McSkimin are in general use. For the high frequency range the shear reflectance method of McSkimin is in general use. For very high frequencies, the cavity resonator type of drive, developed by Bömmel, has been considered, but has not yet been applied to liquids. These shear wave measurements, combined with more conventional longitudinal wave measurements can completely characterize the mechanical properties of a liquid or solid.

A large number of measurements have been made of the properties of polymer solutions up to frequencies of 100 kc/s and in every case the shear viscosity decreased with an increase in frequency and a shear stiffness occurred for the solution which increased as the frequency increased. For frequencies up to 105 c/s, the stiffness and viscosity could be accounted for by the theoretical formulas of Rouse–Bueche–Zimm which depend on determining the normal modes of a polymer chain and their coupling to the driven liquid solvent. Over a temperature and concentration range the measured values were in agreement with the Tobolsky–Leaderman–Ferry reduction formula which assumes that all the component stiffnesses increase in proportion to the absolute temperature and to the concentration, while all the relaxation times have the same temperature dependence, i.e. all the component viscosities have the same activation energies.

The Rouse–Bueche–Zimm theory does not introduce any cut off or highest frequency chain segment motion as is usually considered to occur in polymer theory. Hence, the number of segments N for a given polymer chain length is not determined by this theory. The highest frequency measurements at 14 Mc/s are definitely removed from the theoretical curve. By introducing a highest frequency of relaxation for a polymer chain in the Rouse–Bueche–Zimm theory, agreement is obtained with experimental measurement and a shortest chain segment of about 100 monomer units is found for poly*iso*butylene.

Measurements for pure polymer liquids of varying chain length agree with the reduction formulae up to stiffnesses of about 10^8 dynes/cm^2. Above this stiffness a final chain segment of about 100 monomer units is

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again found for poly*iso*butylene which has a stiffness which decreases with an increase in temperature as is usually found in a polymer solid. Hence, the reduction formulae for shear stiffness do not hold in this region. It is found, however, that the effective shear viscosity does obey the reduction formula quite closely. Since this depends mostly on the activation energy for the separate normal modes, it appears that this remains constant. Since all the normal modes depend on an integrated movement of a number of shortest chain segments, this result might be expected.

Cavitation and Sonoluminescence

By P. JARMAN

There is now sufficient knowledge about sonoluminescence to support further speculation about its origin. Some of this knowledge is certain : sonoluminescence occurs in engassed liquids when they are cavitated by intense sound waves, it occurs preferentially in the pressure antinodes of a stationary wave system but it will occur wherever there is cavitation ; its intensity is strongly dependent on the nature and temperature of the liquid and also on the nature of the dissolved gas ; its spectrum is a continuum stretching from the ultraviolet into the near infrared except in strong solutions of certain salts when some line and band spectra appear ; its intensity is not in general affected by small proportions of liquid impurities but the addition of a few drops of carbon tetrachloride or of carbon disulphide considerably enhances the sonoluminescence from water. Sonoluminescence generally occurs as a discrete flash of light regularly once every sound cycle and it is accompanied by chemical changes in the liquid phase ; the luminescence, however, appears in the gas or vapour phase of the cavitating bubbles. Secondary flashes of luminescence have been found and there is a unique report of luminescence from hydrodynamically induced cavitation.

A brief description is given of recent experiments of the author including an attempt to detect luminescence from hydrodynamically induced cavitation. The phase of the discrete flashes of sonoluminescence with respect to the sound pressure cycle is still uncertain as the problem of sonically induced cavitation, that of determining the motion of a gas filled or vapour filled bubble for a succession of sound pressure cycles, has yet to be solved.

Sonoluminescence cannot be satisfactorily ascribed to electrical microdischarges within the cavitating bubbles nor can it entirely be due to chemical reactions that take place at the same time. It more closely resembles the light emission in shock tubes than that from discharges and flames ; in particular, recent experiments show that there is a close resemblance between the spectra of sonoluminescence and the spectra of shock tube luminescence. It is plausible therefore that sonoluminescence might be due to microshocks within the cavitating bubbles. This hypothesis can be examined in the light of current theories of cavitation : convergent microshocks appear to be possible during the final stages of the collapse of the bubbles. Sonoluminescence does in any case appear to be thermal in origin and it can probably only occur in predominately gas-filled bubbles.

Further studies of sonoluminescence will be of value in the understanding of cavitation phenomena and of the nature and properties of gas-filled solutions.

Fluctuations in Liquids

By R. FURTH

If a liquid is subjected to external forces it will in general exhibit the phenomena of flow and of wave propagation on a microscopic scale which are the subjects of rheology and acoustics respectively. In addition, however, and even in the absence of external influences, a liquid is always subject to spontaneous fluctuations on a microscopic scale which may be regarded either as an irregular flow or a random superposition of waves.

In the following it is intended to show that these fluctuations constitute an essential feature of the " structure " of liquids, and to indicate how they are mathematically described and how they can be investigated theoretically and experimentally.

First it must be emphasized that what is meant by the " structure " of a material body depends on the scale of the magnification. On a 1 Å scale the structure of matter is identical with its " molecular " structure which consists in the arrangement in space of the atomic constituents. On a scale of, say, 1000 Å we can regard matter as almost continuous and describe its structure by certain continuous functions $\xi(r)$ which represent the dependence of certain " macroscopic parameters " on the space-co-ordinates.

On the 1000 Å scale a material body could in principle be completely homogeneous and thus have no structure at all. In actual fact, however, a body which appears to be homogeneous on a macroscopic scale can never be completely structureless on the 1000 Å scale because of the irregular thermal movement of the constituent particles which result in irregular fluctuations of the macroscopic parameters in space and time. Apart from this " transient " structure, matter in the crystalline or the glassy state also invariably exhibits quasi-permanent structure features on the same scale which are usually referred to as " texture ". Well known examples are the grain and fibre and the " micelle " structures. In contrast a fluid substance has no texture except in the neighbourhood of certain " critical " points.

In all the mentioned cases the structure on a 1000 Å scale has a " random " character and the functions, which describe it mathematically are so-called " stochastic " functions of space and time. In a macroscopically homogeneous body the deviations $\delta\xi$ from the average fluctuate randomly in space at any particular moment, but there exists a correlation between the values $\delta\xi$ and $\delta\xi'$ in two volume elements a distance r apart. The " correlation function " $g(r)$, defined by

$$g(r) = \frac{\overline{(\delta\xi \,.\, \delta\xi')}}{\overline{(\delta\xi)^2}} \qquad (1)$$

where the bars indicate space averages, is an ordinare function of r and is time independent if the body is in a state of microscopic equlibrium. The structure of a textureless fluid on the 1000 Å scale is completely described by the correlation functions of the various relevant macroscopic parameters.

Any stochastic function $\xi(r)$ can be resolved into a continuous spectrum of plane waves with wave vectors k and amplitudes $a(k)$ and random phases. One can then introduce a " spectral density function " $f(k)$ such that $f(k)dk$ measures the total intensity of all these waves in the wave number interval dk. It can be shown that the functions $g(r)$ and $f(k)$ are cosine. Fourier transforms of each other :

$$g(r) = \iiint f(k) \cos(2\pi kr)\, dk$$
$$f(k) = \iiint g(r) \cos(2\pi kr)\, dr \qquad (2)$$

Theoretical information on the correlation function $g(r)$ may be obtained from the kinetic theory of liquids, but owing to the very great complexity of this theory only qualitative general conclusions can be drawn. It can for example be shown that the density fluctuations in a liquid are propagated from one volume element to another in the form of heavily damped waves with a certain average wavelength. It follows from the definition (1) that $g(r)$ must have a shape which indicates positive correlation for $r<r_0$ and negative correlation for $r>r_0$; this amounts to a kind of " grain " structure of average size r_0. This is easily understood if one realizes that a surplus of density in one volume element must cause a deficiency in density in the surroundings and vice versa.

It ought also to be possible to obtain the function $g(r)$ from a knowledge of the spectral density function $f(k)$ by means of the relations (2), but again this is hardly practicable on account of the difficulties of the statistical mechanics of liquids. Qualitatively it can be seen, however, that on the whole only acoustic waves with comparatively long wavelengths, i.e. small wave numbers will contribute to the spectrum as those with very short wavelength are very heavily damped. As a result it follows from (2) that $g(r)$ must have a shape indicated by the above.

In order to investigate the structure of a liquid on the 1000 Å scale experimentally one can make use of the scattering of mechanical and electromagnetic waves of suitable wavelength in the liquid. No scattering of acoustic or optical waves takes place in a material which is strictly homogeneous on the 1000 Å scale, but any structure on this scale must necessarily result in the scattering of harmonic waves with an intensity I depending on the wavelength λ and the scattering angle θ and the size and shape of the structure elements. If $\lambda \gg r_0$ Rayleigh's law $I \propto \lambda^{-4}$ will be obeyed and the scattering is symmetric in the forward and backward directions, but otherwise the shape of the function $I(\lambda\, \theta)$ will depend characteristically on the structure of the scattering medium.

It can be shown from general principles that

$$I = \frac{\text{const.}}{s} \int_0^\infty g(r) r \sin(sr) dr, \quad s = \frac{4\pi}{\lambda} \sin\frac{\theta}{2} \qquad (3)$$

The correlation function $g(r)$ can thus be computed from the inverse transform to (3), i.e.

$$g(r) = \frac{\text{const.}}{r} \int_0^\infty s\, I(s) \sin(sr) ds \qquad (4)$$

The Role of Viscosity in Spherical Motion of Liquids

By H. G. Flynn

One of the topics of interest in connexion with the study of cavitation is the effect of viscosity on the collapse of bubbles containing a very small amount of gas. It appears that both the first and second viscosity coefficients are involved, and it is the difficulty of determining the latter which is the stumbling block in estimating the above effect. For a non-viscous compressible liquid in spherically symmetrical motion the exact solution of the Lagrangian equations describes a motion that is also one of uniform dilatation. This solution appears also to be valid for a similar motion in a viscous, compressible liquid provided that the adiabatic curves for the liquid are not too strongly dependent on the exact value of the entropy.

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If the motion is both one of spherical symmetry and of uniform dilatation the viscosity terms vanish from the momentum equation which describes the motion of a viscous, compressible liquid. The effect of viscosity appears only in components of the stress tensor and in the dissipation function, and these then assume an extremely simple form. In principle, this leads to a possible method of determining the second coefficient of viscosity. For this purpose it would be necessary to construct a spherical piston to follow a particle path computed from the above solution. If the stress in the liquid at the interface can be measured then, for a liquid whose first viscosity coefficient is known, all quantities appearing in a simple expression for the radial component of the stress tensor can be calculated except the second coefficient of viscosity.

Tuesday, 15 September—The Glassy State

Sources of Delayed Elasticity in Glasses

By R. W. Douglas

Examination of the data in the literature in the light of some recent measurements of the anelasticity of glasses and the release of stress in the annealing range has enabled four sources of apparent delayed elasticity to be isolated. These are :

The bulk viscosity, which is associated with the slow changes of configuration which occur following some changes of temperature or pressure in the transformation range. The transformation range is here defined as that range of temperature at the upper limit of which changes of configuration occur too rapidly to be observed, and the lower limit of which is that temperature at which the changes of configuration are so slow as to be unobservable in the particular experiments under consideration.

The second and third processes arise from the stress-induced diffusion of oxygen and sodium ions. The association of one peak in the anelastic spectrum with sodium ions has been established for some years, but only recently has experimental evidence been obtained to confirm that a second peak, which occurs particularly in binary silicate glasses and at a higher

temperature than the sodium ion peak, is associated with oxygen ion diffusion. Unfortunately no good values are available for the diffusion of oxygen ions, and the confirmation is indirect, having been obtained by measurement of the activation energy of the attack of anhydrous sulphur dioxide on the glass surfaces. In this reaction it is suggested that sodium and oxygen ions diffuse together, the slower-moving oxygen ions controlling the rate of diffusion.

The fourth process is not so well understood. In the literature there is no clear-cut distinction between true delayed elasticity, which is now thought to be a fourth process, and the change of viscosity with time in the transformation range. It now appears, however, that the background obtained in the anelasticity experiments on which the sodium and oxygen ion peaks are superimposed is a true delayed elasticity, and that the values of about 10^{20} poises which have previously been obtained for the viscosity of glasses at room temperature are properly to be attributed to a delayed elasticity and not to true viscosity.

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Dynamic Mechanical Properties of Associated Liquids in the Liquid and Glassy State

By T. A. Litowitz

The physical properties of a liquid differ from those of an amorphous solid mainly because the liquid structure can change with pressure and temperature. The specific heat, thermal expansion coefficient and compressibility, are larger in a liquid than in a solid because of the structural change contributions. It has been suggested by many investigators that the glass transition is simply a structural relaxation phenomenon where the time necessary for the molecular processes contributing to structural rearrangement becomes larger than the time duration of a normal experiment. Thus in the glassy state the structural rearrangements do not contribute to the properties of the substance. One does not need to study the substance in the glassy state to investigate these structural relaxation properties. By drastically reducing the time scale of the experiment one can measure glass-like properties of a liquid of temperatures higher than the normal glass transition temperature.

In practice it is very difficult to decrease the time scale of an experiment measuring either specific heat or volume expansion to less than several minutes ; however, by using sonic and ultrasonic waves one can measure sound velocity and thus compressibility or elasticity from very long times or static measurements down to times as short as a hundredth of a microsecond or less. Using these short times one can make a glass transition occur at temperatures above the normal glass transition. This glass transition occurs when the period of the ultrasonic wave is shorter than the relaxation time associated with the structural changes. Using these high frequency ultrasonic waves one can measure the shear rigidity and compressibility of the non-crystalline liquid lattice and compare these properties with the values found in normal solids. Because of the intimate connexion between the kinetics of the glass transition and the viscous relaxation effects an understanding of relaxation phenomena in liquids is useful in explaining certain aspects of the glass

transition. For example, it was at first thought that the temperature at which the normal glass transition occurs is determined by the value of the shear viscosity but more recently it has been realized that the volume viscosity and volume relaxation effects play an important role. Ultrasonic absorption data serve as a useful means of determining the volume viscosity of liquids. Using ultrasonic data we have investigated the relationships between the shear and volume viscous processes in associated liquids.

Associated liquids exhibit two distinct loss mechanisms for ultrasonic waves. One of these is related to the shear viscosity of the liquid and the other is due to the structural type of volume viscosity. It is interesting to note that those substances which tend to form a glass always exhibit a structural type of volume viscosity in the liquid state. The " association " in the liquids we have studied is due to directed forces between molecules, known as hydrogen bonding. The presence of these forces enhances greatly the degree of order in the liquid and makes the structural relaxation an important effect in the volume viscosity.

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We have made visco-elastic measurements on four different associated liquids, butanediol 1 : 3 ; hexanetriol 1 : 2 : 6 ; 2-methyl pentanediol and glycerol, and from these we have come to certain conclusions about this type of liquid. These are as follows :

(1) The relaxational part of the compressibility of these liquids seems to vary from about 20 to 60 per cent of the total static compressibility. The velocity dispersion data showed increases in velocity of as much as 70 per cent in going from low to high frequency, which is considerably larger than found in any other type of ultrasonic loss mechanism. The shear rigidity was measured in each one of these liquids and it was found that the value of the shear modulus was about 20 to 30 per cent of the compressional modulus. In this connexion it is interesting to note that the ratio of shear to compressional modulus in the liquids was very close to the values found in typical solids, even though the magnitude of the moduli found in the liquids was about factor of 10 smaller than found in typical solids.

(2) It was found in every case that a distribution of relaxation times was necessary to account for the data. It was interesting to note that the shear data could be accounted for using a symmetric or Gaussian distribution of times whereas the compressional data needed an asymmetric distribution of relaxation times. This distribution is similar to that found for polymers with the exception that the distributions found here are considerably narrower than one usually finds in polymeric liquids.

(3) The average structural and shear relaxation time in these four associated liquids was found to be very close in value departing by a maximum of a factor of 4 and in two of these liquids—glycerol and butanediol 1 : 3 the values were within 20 per cent of each other. In addition it was found that the relaxation times had the same temperature dependence which was not unexpected since the volume and shear viscosities had the same temperature dependence.

(4) In considering the data it was found that at high frequencies the absorption could not be accounted for by the same distribution which

was used to fit the velocity data. At frequencies well above the dispersion region it was found that an attenuation set in which was independent of frequency. This appears to be a characteristic of these liquids at very high viscosities or high frequencies. At this time there seems to be no acceptable mechanism to explain this type of loss.

The Movement of *Cyclo*hexyl Groups in Glassy Polymers

By J. HEIJBOER

Poly(*cyclo*hexyl methacrylate) has a secondary mechanical dispersion region which is located at about −80° C for 1 c/s and at about −25° C for 1000 c/s. In a previous paper (J. HEIJBOER, *Kolloidnyi Zh.*, 1956, **148**, 36) it was shown that this mechanical dispersion is typical for the *cyclo*hexyl group. The dispersion could be attributed to a redistribution of the *cyclo*hexyl rings over the two chair configurations which are possible.

The present paper gives further information about the influence of the chemical composition of *cyclo*hexyl-containing polymers on the mechanical damping peak. Also dielectric measurements are reported, especially for poly(chloro*cyclo*hexyl methacrylates). More insight has been obtained into the factors which determine the height of the mechanical damping peak. The molecular mechanism suggested previously was confirmed.

Dynamic mechanical measurements have been performed in two frequency regions : in the 0·3–3 c/s region the samples were subjected to free torsional vibrations ; in the 200–2000 c/s region the samples were subjected to forced flexural vibrations.

The following chemical modifications of *cyclo*hexyl-containing polymers were effected :

(1) *Cyclo*hexyl methacrylate has been copolymerized with several types of monomers, such as those having more or less flexible side chains and those containing strong polar groups (nitrile-group, acid-group).

These modifications do not influence the location of the mechanical loss peak in the temperature frequency diagram.

For a given *cyclo*hexyl content the effect on the height of the peak is only slight. In a series of *cyclo*hexyl methacrylate-methyl methacrylate copolymers, the height increased nearly in proportion to the *cyclo*hexyl content.

(2) One of the *cyclo*hexyl methacrylate copolymers was plasticized by dibutyl phthalate. Again the location of the peak remained the same, but the height was diminished. This is in contrast to the effect of this plasticizer on the secondary damping maximum in poly(methyl methacrylate).

(3) Internal plasticization has been realized by using a *cyclo*hexyl acrylate (instead of *cyclo*hexyl methacrylate) polymer. In this case the main polymer chain was more flexible.

The location of the peak remained the same, but the peak was higher at the same *cyclo*hexyl content.

(4) The *cyclo*hexyl ring itself has been modified by introducing a methyl group in the paraposition (4-position). This modification of the ring decreased the height of the maximum to a great extent ; however, its location remained the same.

(5) Instead of being fixed to the polymer chain, the *cyclo*hexyl group can also be present in a small molecule of a plasticizer. Di*cyclo*hexyl phthalate, *cyclo*hexyl bromide and *cyclo*hexyl chloride were tried as plasticizers in poly(methyl methacrylate). They all show definitely the *cyclo*hexyl peak. The peak is the most pronounced for the phthalate, whereas for the bromide and especially for the chloride it is only small. The location is slightly different, e.g. in the case of di*cyclo*hexyl phthalate a shift of 5 °C to lower temperatures has been found.

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All the types of chemical modifications mentioned above do not influence the activation energy of the mechanical process ; it is in all cases about 12 kcal/mole. This means that the movement of the *cyclo*hexyl ring is not influenced by the molecular environment ; the potential barrier in the *cyclo*hexyl ring is the governing factor and this barrier is in all cases the same.

As to the height of the peak : for the *cyclo*hexyl-containing plasticizers, the peak is the more pronounced for the bigger side group. For the para-substituted *cyclo*hexyl group, one end of which is attached firmly to the polymer chain, the situation is different. A higher mechanical peak might be expected than for the non-substituted ring. However, the opposite is the case. This can be explained by supposing that part of the rings are blocked by the environment ; these rings cannot move at all and do not give rise to energy dissipation. However, as far as the groups can move, they do so with the same ease as in the non-substituted ring. Consequently the location in the temperature frequency diagram remains the same.

Dielectric measurements were performed on poly(4-chloro*cyclo*hexyl methacrylate) and poly(2-chloro*cyclo*hexyl methacrylate). The dielectric loss maxima of these chlorine-substituted polymers are located at the same temperature and frequency as the mechanical loss maximum of poly(*cyclo*hexyl methacrylate). However, the dielectric loss peak is much higher for the poly(2-chloro*cyclo*hexyl methacrylate) than for the poly (4-chloro*cyclo*hexyl methacrylate). This confirms the suggested molecular mechanism, as the change in dipole orientation for the transition from one chair configuration to the other is much more pronounced for the 2-substituted ring than for the 4-substituted ring.

Another confirmation of the molecular mechanism has been obtained from mechanical measurements on poly(methyl methacrylate) plasticized with 1 : 1 dichloro*cyclo*hexane. No *cyclo*hexyl damping peak has been found in this polymer. If the suggested molecular mechanism is correct this is as should be expected, as for this *cyclo*hexyl derivative the two chair configurations are identical.

A preliminary study has been made of another type of six-membered ring, the dioxane ring. As a model compound, bisdioxane was used, which contains two saturated six-rings, each with two oxygen atoms. The measurements were performed on poly(methyl methacrylate) with bisdioxane as a plasticizer.

A dielectric as well as a mechanical loss peak has been found, both being located near the *cyclo*hexyl peak. For this maximum however, the locations of the electrical and mechanical maxima in the frequency-temperature diagram do not completely coincide. In comparison with the *cyclo*hexyl peaks, there is also a slight shift to lower temperatures. This mechanism differs also from the *cyclo*hexyl mechanism in that the height of the electrical loss peak increases with increasing frequency. The movement of the dioxane ring appears to be influenced by the molecular environment.

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Time Dependent Physical Properties of Rigid PVC after Quenching

By D. R. Reid, R. A. Horsley and R. F. Eagling

The mechanical properties of rigid PVC at room temperature have been found to be considerably affected by the rate of cooling of the sheet through the softening range (i.e. near the glass temperature) (R. A. Horsley, *Plastics Progress*, p. 86, Iliffe, London, 1957). Rapid cooling produces a material of lower elastic modulus and yield stregth, whereas very slow cooling results in a higher modulus and yield strength accompanied by a tendency towards brittle failure under impact.

It is also found that the state induced by rapid cooling is quasi-stable and that the mechanical properties tend to revert slowly toward the values characteristic of slowly cooled material. The rate of reversion is influenced by the presence of plasticizers and by their specific nature. These changes have been observed using conventional tensile and impact test methods as well as by measuring changes in dynamic elastic modulus and internal friction.

Related changes have been found in the study of tensile creep of rigid PVC. It has been found that normal " annealed " rigid PVC exhibits " Andrade creep " i.e.

$$\text{creep strain} = \beta t^{1/3};$$

the constant β has been found to vary with stress S and temperature T according to the empirical expression :

$$\beta = \beta_0 \operatorname{Sinh} \frac{\alpha S}{\theta - T} \exp \frac{[N]}{\theta - T}$$

the significance of which will be discussed.

Quenching initially causes an increase in creep rate but this diminishes and after about 2 days the creep rate settles down to a value about 10 per cent higher than that of an annealed specimen. However, if the specimens are allowed to stand unstressed at room temperature for longer times before testing, the creep once more obeys Andrade's equation but with higher values of β than the annealed specimens.

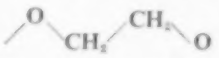
The Interpretation of Transition Phenomena in Polymethylene Terephthalate and Related Polymers

By G. Farrow, J. McIntosh and I. M. Ward

In an attempt to understand the nature of the so-called glass transitions of polyethylene terephthalate, a series of polymethylene terephthalate polymers has been examined from the viewpoint of dynamic mechanical properties, nuclear magnetic resonance spectra, infra-red spectra, and X-ray measurements.

Each of these polymers shows three transitions if it is assumed that the first order melting point is a transition. These are labelled α, β, etc. in descending order of temperature and of loss maxima i.e. α corresponding to the melting point ; β in general will correspond to the glass transition. The dynamic measurements on these polymers showed three transitions of which the β-transition is clearly the glass transition ; a notable feature is that the temperature interval between the β- and γ-peaks, within experimental error, is a constant 145 °C. The loss patterns are similar inasmuch as the β-transition is more marked and is steeper on the lower temperature side than on the high ; the γ-transition, however, is steeper on the high temperature side in the lower members of the series but this reverses through the series for it to become steeper on the low temperature side in the high members. Poly-*iso*phthalic anhydride shows only a definite α- and β-transition ; the γ-transition is hardly discernible. The evidence taken together suggests that the γ-transition is connected with motions in the aliphatic part of the chain. Further evidence is adduced to suggest that the β-transition is connected in some way with the phenylene carbonyl bond.

The nuclear magnetic resonance spectra of various samples of these polymers have been measured within the temperature range 90 °K to 465 °K. The measured second moments at 90 °K are greater than the values calculated for wholly crystalline samples. This is attributed to the tangling of molecules in the amorphous regions and the consequent very close approach of some of the hydrogen atoms. It is also evident from the small change in second moment occurring over the temperature range of the γ-transition that this must be restricted to small molecular motions. The β-transition on the other hand must be associated with a considerable rotation of the methylene groups in the amorphous regions.

A further approach to the interpretation of dynamic loss measurements has been made by use of infra-red and X-ray data. Detailed assignments of the infra-red absorptions of polyethylene terephthalate and related compounds suggests that the major differences between the infra-red spectra of amorphous and partially crystalline samples of polyethylene terephthalate are due to rotational isomerism. In particular it is proposed that an additional preferred configuration of the  group exists in the amorphous regions of the polymer. Since crystallization sets in above the high temperature transitions it is reasonable to infer that this transition is associated with at least this configurational change.

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Detailed X-ray and optical examination of single crystals of cyclic tri(ethylene terephthalate) show that in the cyclic trimer molecule the benzene rings are co-planar. Examination of molecular models shows that this implies that the carboxyl groups are placed in *cis*-positions with respect to the benzene rings. Thus, the configurational changes may be greater than those suggested by the infra-red data and may involve the phenylene carbonyl bond in addition to the glycol residue.

X-ray diffraction patterns of all these polymers at both high and low temperatures show that there is no change in their crystal structures. The considerable rotations which take place at high temperatures must, therefore, occur in the amorphous region of the polymer.

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The most satisfactory explanation of these transitions taking into account nuclear magnetic resonance, infra-red and X-ray data is that the γ-transition involves some very restricted rotation of the glycol residue and the β-transition a considerable rotation of the residue, probably involving the phenylene carbonyl bond as well. This explanation then accounts for the fact that the large change in nuclear magnetic resonance second moment occurs on the verge of the β-transition as well as the fact that configurational changes involving the glycol residue take place during crystallization.

Summaries of Papers read at a Joint Meeting of the British Society of Rheology and the Faraday Society on Flow Properties of Blood and Other Biological Systems held at the Oxford University Laboratory of Physiology on 23 and 24 September, 1959

Physical Properties of the Reproductive Tract in Relation to Pregnancy

By M. L. R. Harkness and R. D. Harkness (Department of Physiology University College, London, W.C.1)

The connective tissues of animals behave in short term experiments as if they contained a rigidly linked collagenous network of finite size. However, under certain circumstances, they can show plastic properties and flow slowly under mechanical stress. The shape of tissues can be changed by localized destruction combined with redeposition, and this is what happens in growth of bone, but there is evidence that in other tissues plastic flow is of importance.

It is probable that plastic adaptation of collagenous tissues is of widespread importance in growth processes. Our own interest is the nature of the change in the properties of the lower end of the uterus which enables the normally narrow and rigid canal of the cervix uteris to allow the passage of so large an object as a mature foetus at the end of pregnancy. This tissue shows at the end of pregnancy a plastic extensibility considerably greater than we have found so far in any other tissue.

Methods

Excised rings of tissue from rat's cervix were pulled out between two thin stainless steel rods, one fixed and the other movable, round which they formed a belt. In most cases the relative proportions of the tissue which was at the ends over the rods were small enough to make it possible to ignore the geometrical complications there and to regard the tissue as a straight length pulled at between its ends. Tissues were tested under simulated physiological conditions, i.e. immersed in oxygenated Ringer Locke's solution, usually at 37°C. Effects were recorded by a lever attached to the movable rod and writing on a smoked drum. Loading was done by hand by placing weights in a pan.

Two types of experiment were done ; first, length–tension curves were obtained by increasing the load rapidly (minutes) in steps at constant rate until the tissue ruptured ; second, loads normally of the order of a tenth to a fifth of the breaking load were left on for long times (hours).

In all cases the total collagen content of the tissue was estimated so that results could be related to tension per unit cross-sectional area of collagen calculated from the length of the tissue.

Length–tension relations

The slope of the length–tension curve diminishes at first as tension is raised and then usually becomes constant, giving an approximately linear relation between length and tension till near the point of rupture when the slope increases again. The linearity of the middle part of the curve is produced by the combination of two processes which change in opposite ways with tension. The increase in length under load is partly elastic (and immediately reversible) and partly plastic, but the analysis of these effects has not been pursued. The main finding which emerged was that cervixes at the end of pregnancy differed from normal principally in that they behaved as if their inner circumference was three to four times larger ; also the breaking tension per unit cross-sectional area of collagen was somewhat reduced.

Effect of prolonged loading

In the non-pregnant rat a constant load produced extension at a rate which diminished with time for several hours. The relation of length to the logarithm of time was approximately linear. At the end of pregnancy the effect was similar at first but the rate of extension, instead of continuing to diminish, became constant so that the length was linearly related to time. This slow extension would continue up to the point of rupture which was usually preceded by some increase in rate. We have taken as the measure of this slow extension the value of K/l_0 where K is the slope of the mean part of the curve and l_0 is the length at zero time obtained by extrapolation. K increased with load per unit cross-sectional area of collagen, but the relation is not a simple linear one judging from our results so far. No evidence was obtained to suggest that K was zero at a load above zero, i.e. there was no evidence of a yield point. K was affected by temperature with a Q_{10} of about 2 in the range 17–37 °C.

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Variations in slow extension under different physiological circumstances

The fastest rates of extension under prolonged loading have been found in the cervix at the end of pregnancy. The extensible condition found at that time is lost within 24 hr after parturition. Thus, it is clear that the animal possesses a mechanism for varying this property quite rapidly. A number of other tissues show the property as well as the cervix, e.g. uterine horn, gut and skin.

Coagulation of Milk

By G. W. Scott Blair (National Institute for Research in Dairying, Shinfield, Reading)

This paper describes measurements of changes in the elastic and viscous parameters of the gel which forms when milk is coagulated by rennet[1]. The apparatus is modified from that designed by Saunders and Ward [2] for gelatine.

The milk (50 ml) containing rennet and, if necessary, added calcium, and adjusted to the desired pH with lactic acid, is placed in a U-tube in a thermostat, normally at 32°C. The walls of the U-tube are roughened, either mechanically or with hydrofluoric acid, to increase the adherence of the gel. One side of the U-tube is attached to a controlled air pressure system with suitable manometers and the other, to a horizontal capillary of bore about 1·6 mm (" the recorder ") containing a small index of coloured alcohol whose position can be read on a scale. A four-way stop-cock enables pressures to be applied (normally) alternately to each side of the column of setting milk.

Once the milk has started to set, pressures (P) are applied every few minutes for 1 min and elastic recoveries (ϵ) are recorded after a further 2 min. During setting, pressures are progressively increased so as to give approximately the same recorder readings after 1 min loading for all ages of the gel.

From an equation exactly analogous to that of Poiseuille, the rigidity modulus (G) can be calculated from P, ϵ and the dimensions of the apparatus. After a time, syneresis generally terminates the experiments but, except in the earliest stages of setting, a plot of G/log t (where t is time after addition of rennet) gives remarkable straight lines. The significance of this linearity is discussed.

If the gel is allowed to set for long enough for experiments to be done within a time during which further changes may be ignored, its rheological properties may be studied. Creep and recovery curves show that, under such simplified experimental conditions, the gel reacts as an almost perfect Burgers Body. Its behaviour may therefore be described in terms of four parameters : (1) G_1, an immediate elastic modulus ; (2) G_2, a modulus of delayed elasticity ; (3)η_1, a creep viscosity and (4) η_2, a damping viscosity for G_2. These parameters have been independently measured and all appear to be linearly related to log t. The intercepts of these straight lines, extrapolated to the log t axis, correspond with times always slightly ($\approx$20 per cent) greater than the time when coagulation is first observed in the milk (coagulation time, t_0). It is important that the slopes of these curves, e.g. G_1/t, and their intercepts, are quite

independently affected by various processes by which the milk may be treated.[3] In cheese-making practice, only t_0 is measured, the subsequent rates of setting being ignored.

Under more complex experimental conditions, milk gel requires more than four parameters for its description. When loads are progressively increased and decreased, characteristic hysteresis loops are obtained which do not follow the Burgers model. These hysteresis loops show a progressive work-hardening and, on reversal of the direction of stressing, a softening (Bauschinger effect).[5] If a stress is applied for a long time in one direction, followed by a short stressing in the opposite direction, on release of this latter stress, the gel shows an " elastic memory ", i.e. a reversal in direction during the course of its elastic recovery. This phenomenon requires another elastic and viscous unit to be added to the Burgers model.

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Under conditions of constant strain relaxation, still more complex conditions obtain, since there is found to be a continuous distribution of relaxation times. Under optimal conditions, however, this distribution is very exactly log-normal in character.[6] A plot of S/S_0 (when S is stress at time t and S_0 is initial stress) against t on logarithmic probability paper gives remarkably straight lines, indicating a Wiechert distribution.[7]

Under still more complex conditions, power-laws containing one or more terms are needed to account for creep and relaxation behaviour.

These experiments show clearly the practical importance of measuring independent parameters in studying the phenomena of milk coagulation. They also demonstrate the usefulness of simple rheological models where these are applicable, but also their limitations. The complexity of the required model depends on the experimental conditions.

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The Flow-birefringence of Purified Cervical Mucoid

By R. A. Gibbons and F. A. Glover (National Institute for Research in Dairying, Shinfield, Reading)

The mucin secreted by the cervix of the uterus of mammals changes in rheological properties with the sexual cycle. At oestrus it is a thin, copious visco-elastic gel, something like the white of an egg, whereas at dioestrus and in pregnancy it is scanty and thick, sometimes having a consistency almost like that of rubber[1]. In order to study the factors underlying these rheological properties it is necessary in the first place to separate the substance or substances responsible for them from those

which are irrelevant in this context, and to do so without destroying these properties. Using pooled samples of bovine oestrus mucin and pregnancy mucin a satisfactory fractionation has been worked out and the products—from both samples—have been found to be, chemically, mucoids of the blood-group substance type.

Though forming voluminous gels in water, these mucoids may be dispersed in saturated aqueous calcium chloride/ethanol mixtures (9 : 1 by vol.) and in this solvent the birefringence has been studied. The pregnancy mucoid gave anomalous curves. The birefringence, initially zero, was found to be positive at low shear rates, increasing to a maximum and then decreasing with increasing shear to become zero again at about 80 sec^{-1}. Thereafter it became negative and continued to increase negatively with increasing shear, giving curves approximately parabolic in shape. TSVETKOV[2] found analogous curves for the birefringence of high molecular weight polystyrene in dioxan, and he later[3] offered the following explanation. The birefringence of a random coil molecule undergoing distortion in a shear gradient arises from two sources.

(i) Form birefringence ; due to the ellipsoidal shape of the domain occupied by the distorted macromolecule which is always positive. This is the same as the internal field effect which has been studied by COPIC[4] ; and

(ii) the intrinsic birefringence due to the preferred orientation of segments of the chain in the direction of elongation. This is analogous to strain birefringence in an isotropic solid and may be positive or negative, but if the latter it implies that the molecule is more easily polarizable across the chain than along it. The intrinsic birefringence is a relatively simple function of the rate of shear, viz. $1 + \beta^2$ where β is itself a function of the rate of shear and for a given molecule is a constant multiple of it. The form birefringence, however, is a more slowly varying function of the rate of shear ; according to TSVETKOV and FRISMAN[5] it reaches a maximum when the " axial ratio " is approximately 4, whereas COPIC[4] suggests it should increase without limit, though more slowly than the intrinsic birefringence. Qualitatively the result is in either case the same ; the intrinsic birefringence ultimately becomes greater than the form birefringence and, if the intrinsic birefringence is negative, clearly this will give rise to a variation of birefringence with rate of shear of the form found.

The orientation angle/rate of shear curves are also anomalous; the orientation angle, χ, initially positive, rapidly becomes zero and then negative, when the birefringence becomes zero and the cross of isocline is no longer visible. When it becomes visible again χ is positive, rapidly decreases with further increase in shear rate and then decreases more slowly. FRISMAN[6] has recently published orientation angle curves for polystyrene in dioxan which are of the same form. They may be interpreted on the assumption that the optic axes for the two sources of birefringence are not coincident, and the relation of SADRON[7] may then be used to explore the resulting orientation angle curves. If the birefringences due to form effect (θ_f) and to the intrinsic birefringence (θ_f) vary with rate of shear in the manner indicated, and the orientation of the optic axis of the form birefringence (ϕ_f) to the flow lines differs

from the orientation of the optic axis of the intrinsic birefringence (ϕ_i), theoretical χ/rate of shear curves may be constructed. It may be shown that if $\phi_i > \phi_f$, curves of the observed form are obtained.[5] A consideration of the form of the curve as ϕ_i approaches ϕ_f is of interest and shows that the curves found are of the predicted shape. The curves of FRISMAN[6] show this more clearly than those found in this investigation.

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Some Rheological Properties of Bronchial Mucus and Mucoprotein

By J. C. WHITE and P. C. ELMES (Post Graduate Medical School of London Du Cane Road, London, W.12)

In the absence of an acute exacerbation, the excessive bronchial secretion in chronic bronchitis is mucoid in character. The intact mucus, as expectorated, owes its viscidity and tendency to cause respiratory obstruction to a gel structure, the nature of which may be investigated in a number of ways.[1]

Microscopic examination

Although fresh, unfixed mucus appears largely structureless in the optical microscope, the alignment of particulate debris which is evident by phase-contrast suggests orientation. By polarized light, a weakly-positive birefringent fibrous structure is observed. This has been confirmed by fixation and staining by the periodate-Schiff reaction, etc., and also by freeze-drying and examination in the electron microscope.[2]

Orientation of the mucus

The content of solids in the mucus is rather low (1–5 g/100 ml), but dichroism attributable to orientation of the constituent mucoprotein can nevertheless be observed by ultra-violet examination.[3]

Rheological behaviour of mucoid sputum

The intact sputum will not flow through a capillary viscometer, and a falling ball simply passes between the structural aggregates of the material. After homogenization with an equal volume of water, a relative viscosity of about 20 is observed in the Ostwald viscometer, B.S.2. On standing at 20 °C, the relative viscosity rapidly increases three to four-fold; subsequent homogenization again reduces the viscosity, but with some subsequent recovery. This apparently thixotropic behaviour is much less marked if the homogenization is carried out in 0·14 M sodium chloride, and in M sodium chloride the relative viscosity remains at a low value.[2]

Clinical assessment

Obstruction to the respiratory passages is caused by stationary mucus in the gel phase, and estimates of Newtonian viscosity are inapplicable. After unsuccessful attempts to study the whole mucus in rotatory and extrusion viscometers, a simple apparatus to measure a yield-value has been adopted. A 20 ml all-glass syringe is mounted vertically with the sealed nozzle downwards. Both ends of the plunger have been removed, the lower being replaced by a perforated brass disc and the upper left open. The sputum is placed in the water-wetted barrel and the plunger forced below the surface. The weight necessary to initiate sustained movement of the plunger through the sputum is measured at several levels, and recorded as the yield-value in arbitrary units.[2,4]

The assumption is made that this yield-value is proportional to the force necessary to initiate movement of mucus in the small respiratory passages, but since these are variable in size and their lining membrane is ciliated, no attempt at an actual correlation can be made. The results obtained on daily specimens from a group of 35 patients observed for 10 days correlated well with the changes in their clinical condition however. A frequency distribution of the yield-values for the group as a whole on a log scale was slightly skewed to the right as compared with a normal distribution, due to predominance of values between 250 and 650 g, and with an upper limiting value of about 1,000 g.

Viscosity of the mucoprotein

The aqueous solutions of the mucoprotein exhibit an exponential rise of relative viscosity with concentration up to about 1 per cent and above this gelling occurs. The intrinsic viscosity as determined from extrapolation of the reduced specific viscosities at very low concentrations is about 8 dl/g, indicating a very elongated molecular aggregate with an apparent asymmetry of not less than 150 : 1.

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The Stretch Deformation of Skeletal Muscle

By J. R. Bendall (Low Temperature Research Station, Downing Street, Cambridge)

Living skeletal muscle is unusual in its rheological properties, because not only can it recover rapidly and completely from stretch deformations of up to 130 per cent of the rest length, but it can also contract from this length when stimulated, and will develop very high tension or power. On the other hand, when it dies and passes into rigor mortis, its extensibility under a given load falls about 40-fold, and moreover it will no

longer recover completely from deformations of >2 per cent of its length. This characteristic decrease in extensibility during rigor can now be reversed experimentally in so-called muscle-fibre models, that is in muscle fibres from which all the energy-supplying enzyme systems have been removed. This can be done by adding low concentrations of polyphosphates such as pyrophosphate or triphosphate, or, under special conditions, of adenosinetriphosphate (ATP). The latter is the naturally-occurring substance which acts both as a "plasticizer" to keep the muscle in its easily deformable pre-rigor condition, and as the immediate source of energy for contraction. The plasticizing action manifests itself only if the muscle model is prevented from splitting ATP into adenosinediphosphate and inorganic phosphate. This ATP-ase activity, and the contractility dependent on it, can be inhibited by a number of compounds, of which the relaxing-factor of Marsh (1952) is naturally present in muscle.

The stretch-deformation/time curve of skeletal muscle is long-drawn out and continuous, but for convenience of analysis can be divided into three components ; *A*, rapid ; *B*, moderately rapid ; and *C*, slow, each of which can be approximately expressed by an exponential equation. Components *A* and *B* are virtually complete 6 min after application of the load, whereas *C* is incomplete even after 1 hr. The ratio $A/(A + B)$ lies characteristically in the range 0·85–0·92 for both the stretch and recovery curves of resting and post-rigor muscle, but falls below 0·70 if the muscle has been stimulated just prior to the measurement. Thus, the value of $A/(A + B)$ is a good indication of the state of the muscle, whether it is recovering from a stimulus, or is in a truly resting condition. Similarly, $A/(A + B)$ for the recovery curve, falls very markedly during rigor if the muscle is shortening at the time, but tends to rise above unity for the stretch curve. Even in the complete absence of shortening, $A/(A + B)$ (recovery) falls and $A/(A + B)$ (loaded) rises characteristically during the so-called rapid phase of rigor, and then reassumes its resting value of $\sim$0·90 when rigor is complete. These features of rigor are best illustrated from the continuous record of stretch and recovery curves through the course of rigor obtained by the mechanical loading device of Bate-Smith and Bendall (1949).

The interpretation of the deformation curves of resting muscle and of the changes during rigor in terms of the actual structure of the muscle has up to recently eluded physicists and physiologists alike, but the recent, extremely elegant electron micrographs, obtained by Hanson and Huxley, of ultra-thin sections of muscle fibres have enabled them to propose a model which takes many of these facts into account, and in particular the great reduction in extensibility during rigor.

Mechanical Properties of Fish and Fish Products

By J. J. CONNELL (Torry Research Station, Department of Scientific and Industrial Research, Aberdeen)

The few rheological studies which have been made on fish have been prompted more by interest in its textural acceptability when eaten than by general biological consideration, and the present contribution largely describes attempts either to find methods which will prove useful in measuring texture objectively or to find out why fish flesh behaves as it does.

Although the basic structure of fish flesh is much like any other type of striated, skeletal muscle, it possesses certain peculiarities, one of which, the anatomical division into flakes (myotomes) separated by thin sheets of connective tissue (myocommata) renders almost impossible the application of these rheological methods (e.g. penetrometer, shear force) which have proved useful with meat. Therefore rather indirect methods are being tried, three examples of which will be described.

Dehydrated fish, even of the best quality, is tougher and drier in texture after reconstitution and cooking than fresh fish, and during storage in the dried state it becomes progressively more tough and dry. In order to study the elastic behaviour of one isolated muscle structure, bundles of cells (fibres) were dissected free of connective tissue, reconstituted, and their stretch on loading measured whilst immersed in dilute neutral buffer. The behaviour of the bundles was complex. On loading they at first rapidly extended and then slowly extended a further 5–10 per cent of the initial rapid extension. On releasing the load they were found to have suffered a permanent elongation of about 5–10 per cent of their initial length. Within the limits of about 10 per cent extension, however, they approximately obeyed Hooke's law. Three or four fibre bundles from blocks of freshly prepared freeze-dried cod and freeze-dried cod which had been stored were compared with similar bundles from fresh cod. The apparent elastic modulus increased very rapidly as toughening (as measured by chewing) proceeded. The value of the modulus of fresh cod bundles (ca. $1 \cdot 5 \times 10^8$ dynes/cm^2) is probably too low because the real cross-section of the fibres is overestimated, but it is approximately the same as that found for insect muscle fibres and dried, reconstituted squid muscle fibres. It is about forty times smaller than the value given for rabbit muscle fibres by Bozler.

The dried, reconstituted fibres of cod muscle appeared to possess partial rubber-like elasticity because they developed small reversible increases in tension, unaccountable for by changes in swelling, when the temperature was raised. It therefore seems justifiable to interpret toughening in this system in terms of the well-known relationship between the elastic modulus of rubbery polymers at small extensions and their degree of cross-linking. On this basis the major factor involved in the toughening process is the progressive formation of stable intermolecular cross-links between the protein chains. Substantiation of this view has been obtained from measurements of swelling and of solubility of the fibre proteins in good solvents.

Recently a colleague, Dr. R. M. Love, has evolved a method of measuring the development of toughness in frozen fish samples which involves measuring the degree of comminution produced by disintegrating dissected, thawed muscle cells under standardized conditions. Increased toughness is reflected in a greater resistance of the cells to breaking deformations. It is not yet certain whether this resistance derives from toughening of the cell walls or of the cell contents ; however the rates of toughening at three different cold storage temperatures as measured by this technique correlate well with rates of development of insolubility of the intracellular protein, which suggests that cell contents are more important than cell walls in this connexion. In addition changes in cell walls cannot account for the progressive loss in water-holding capacity which invariably accompanies toughening.

The measurement of such psycho-rheological properties as firmness, jelly-strength, or " Ashi " in products like fish pastes and jellies has not proved straightforward. An interesting development in this field is the application to Japanese fish jellies by Ninomiya of Rivlin and Thomas's method. In this, the characteristic tearing energy of plates of jelly carrying cuts of different known lengths is measured. An advantage of the method is that it is not necessary to have a homogeneous material, a consideration which probably accounts for the fact that correlations between tearing energy and organoleptic quality ratings are better than for some other methods, e.g. penetrometer, elasticity.

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The Rheology of Protoplasm

By L. V. HEILBRUNN (Department of Zoology, University of Pennsylvania, Pa., U.S.A.)

Of all colloidal materials, none is more interesting or more important than the colloid which constitutes the living part of all organisms, plants, animals and human beings. And yet the physical properties of this protoplasmic colloid have been studied relatively little, in spite of the fact that we now have reasonably accurate methods of investigation.

Proper knowledge can only be gained from a study of the *living* colloid —any technique which destroys life will profoundly alter the rheological properties of the colloid. Different types of protoplasm differ, but inasmuch as there is a remarkable basic similarity in the morphological and chemical characteristics of all living cells, it seems fair to assume that the physical characteristics are also similar—and as far as we can now tell, this is broadly true.

Protoplasm, and more particularly the cytoplasm, is a solution of various polymers of high molecular weight with solid as well as fluid particles suspended in it. The amount of suspended material varies for different types of protoplasm ; often the concentration of suspended material approaches the maximum possible for spheres in a fluid.

There are two usual methods for measuring protoplasmic viscosity. One is to observe the movement of granules or other inclusions under the influence of gravity, or centrifugal force, and to apply Stokes' law with appropriate corrections. The other is to apply Einstein's formula for Brownian movement, or some modification of this formula. Both methods agree in showing that, in cells that have been properly investigated, the main mass of the cytoplasmic suspension medium is typically fluid, with a viscosity like that which might be expected for a rather concentrated protein solution. The viscosity of the suspension as a whole can be determined either by the movement of nuclei or other large inclusions through it, or by calculation from the various equations proposed for concentrated suspensions. In many cells, perhaps in all, there is an outer cortex which has the properties of a gel. This is thixotropic. In cells with highly concentrated suspended material, the main mass of the cytoplasm may be dilatant.

The fluid cytoplasm can suddenly stiffen. Such a stiffening occurs following treatment with any of the agents which the biologist has come to recognize as stimulating agents. These agents include mechanical impact, electrical shock, sudden heat, sudden cold, ultraviolet radiation and various chemical substances. All of them cause a liquefaction of the outer cortex and a release of calcium from it. The interior cytoplasm is remarkably sensitive to the calcium released from the peripheral cortex. The stiffening or clotting reaction which follows the entrance of tiny amounts of calcium is similar to the reaction that occurs when vertebrate blood clots.

We have come to believe that in all cells there is an equilibrium between factors which tend to induce clotting and those which tend to prevent or reverse it. Vital activity is largely dependent on rheological changes in the protoplasmic colloid. Thus, cell division is initiated as a result of a clotting reaction which produces the mitotic spindle. This reaction can be induced by agents which throw free calcium ions into the cell interior. Anesthetics or narcotics prevent the clotting reaction, and so do heparin-like substances. Both types of agents can inhibit cell division without destroying the cell. Similarly, muscle protoplasm can be made to clot either by the injection of traces of calcium or by the introduction of tiny amounts of a proteolytic enzyme.

Finally it should be emphasized as strongly as possible that the rheological properties of living protoplasm are in many ways different from those of purified proteins, and they are also very different from the rheological properties of cells which have been mutilated or destroyed. Certainly, theoretically-minded physiologists, pharmacologists and pathologists can profit greatly from proper rheological studies of living cells and their protoplasm.

Flow Properties of DNA Solutions

By J. A. V. Butler and A. B. Robins (Chester Beatty Research Institute, Institute of Cancer Research, Royal Cancer Hospital, London, S.W.3)

The flow properties of nucleic acid solutions are remarkable in that DNA combines the characteristics of a high molecular weight polymer with those typical of a charged polyelectrolyte, whilst at the same time the molecules are relatively stiff. In salt-free solutions much interaction between the molecules occurs, the real origin of which has not been fully established. Moreover a low ionic strength leads to denaturation of the secondary structure of the molecule and for these reasons it is desirable to make measurements in large excess of counter ions, e.g. 0·2 M sodium chloride. Earlier work, however, has shown that, if denaturation is avoided, the molecular dimensions are virtually unaffected by the salt concentration.

Although a number of physico-chemical methods have been applied to the study of nucleic acid solutions, the work described here is concerned solely with viscosimetric measurements which are simple in character. The greater part of the experimental work in the literature has been made by capillary tube methods and the refinements in experimental technique have been considerable. The rotating cylinder (Couette) method is fundamentally to be preferred since low and constant rates of shear are

produced, but it is usually less accurate than the capillary method and not so easily flexible in the range of shear-rate which may be covered without difficult instrumentation.

Viscosity studies of DNA can be made at very low concentrations because the intrinsic viscosity is usually about 60 dl/g. Thus for a concentration of only 2×10^{-3} g/ml in 0·2 M sodium chloride, the relative viscosity would be ca. 1·1 and measurable to $\pm 0{\cdot}7$ per cent by Couette viscometer. It has been found that in deriving the intrinsic viscosity

$$[\eta] = \mathrm{Lt}\,(\eta_{sp}/\text{“}c\text{”}) \qquad \text{as } c \to 0$$

it is preferable to extrapolate a plot of $(\ln \eta r)/c$, rather than η_{sp}/c against c. many DNA samples the slope of the line is only 0·1–0·2, giving a “ Huggins constant ” of 0·6–0·7.

The intrinsic viscosity depends essentially on the volume and shape of the nucleic acid molecule in solution and can be correlated with other physical properties, e.g. sedimentation coefficient. Additional information is obtained by studying the dependence of viscosity upon shear rate at low concentrations where interaction between the molecules is small. The lowest concentration at which useful observations are possible varies inversely with the molecular weight, but for a 5–6 million sample the limit is ca. 2×10^{-5} g/ml. The shear-rate ranges available for study are 0·5 to 35 sec^{-1} in the Couette and from 20 to 400 sec^{-1} in the capillary method. Where the ranges overlap, agreement is obtained between the two methods. The present authors have used a horizontal capillary viscometer, bore 0·5 mm, in which the solution being studied is made to flow under an applied air pressure which is maintained constant during each measurement. The best accuracy obtainable has been $\pm 0{\cdot}3$ per cent in relative viscosity.

No model has yet been proposed for the nucleic acid molecule which can be mathematically treated. Nevertheless certain approximations may be made, e.g. rigid ellipsoid, coil with restricted solvent flow, worm-like chain. From the flow data at different shear rates a value of the rotary diffusion coefficient may be obtained and when this is compared with the values to be expected from the various models, it is evident that DNA approximates much more to a coiled particle than to a rigid one. The behaviour of such a coil in solution is a complex result of deformation and of orientation and the results may be interpreted in a qualitative manner only. However data so far obtained indicate differences between nucleic acids from different sources, which are not so easily detected by static methods of investigation such as light-scattering. The effect of applied shear stress upon the particles in solution is reversible, and some experiments at a very high shear rate (30,000 sec^{-1} for 6 sec) have shown that no permanent loss in viscosity results, though there is some decrease in its concentration dependence.

The Rheology of Blood

By L. E. Bayliss (Department of Physiology, University College. London)

In its normal condition, in the blood vessels of a living animal, blood is a fluid system ; but when it leaves the blood vessels, it sets to a jelly,

or clots. The rheology of the clotting process is a separate problem from that of the blood as a fluid, and will not be considered here. The flow properties of blood are not significantly changed when clotting is prevented, or when the clot is removed by " defibrination ".

When blood is made to flow down a tube, the rate of flow is not simply, and accurately, proportional to the pressure used to drive it, and the ratio of applied pressure (P) to the rate of flow (Q), or the " apparent viscosity ", falls towards an asymptotic value as P (and Q) become greater. This asymptotic value of the apparent viscosity is smaller when the flow is observed in very small tubes (radius less than about 0·1 mm) than in larger tubes. The " viscosity " of a given sample of blood, therefore, unlike that of a " perfect " or " Newtonian " fluid, depends on the way it is measured. The plasma, or serum, in which the red blood cells are suspended has no such " anomalous " property, nor has the optically homogeneous colloidal solution which is produced when the cells are broken up (" hemolysed ").

The flow properties of blood may be interpreted in terms of three phenomena observed in suspensions of many kinds.

(1) If the suspended particles cohere to one another, the force between two layers of the suspension which are in relative motion is not simply proportional to their relative velocity and distance apart (as with a Newtonian fluid) ; in a " Bingham " fluid, for example, a finite " friction " force must be exceeded before any relative motion occurs.

(2) A layer close to the wall of the vessel which contains the suspension is relatively deficient of suspended material, since the particles cannot penetrate into the wall ; owing to this " wall effect " (Vand, 1948), the suspension will " slip " to some extent along the wall of a tube through which it flows.

(3) In a non-uniform velocity gradient, as in a tube, the suspended particles will have a component of velocity directed towards the axis (Saffman, 1956) ; the width of the marginal slippage zone will thus become greater when the suspension flows down the tube.

The line relating the rate of flow of blood in a tube to the pressure applied to one end is not consistent with the assumption that blood is a " Bingham " fluid, and that slippage occurs in a zone whose width could be due only to the wall effect. Direct observation of the optical density of blood flowing in small tubes (M. G. Taylor, 1955) suggests that in a marginal zone, whose width may be up to 20 per cent of the radius of the tube, there is either a deficiency of red cells, due presumably to movement towards the axis, or an orientation of the cells. This has been confirmed, but in dog's defibrinated blood the magnitude of the effect is very variable from one sample to another. Analysis of the pressure–flow relations of blood in tubes of different radius suggests that :

(1) At sensibly zero shearing stress (by extrapolation), there is a slippage zone of width about 1·0 to 1·5μ, which may reasonably be ascribed to the wall effect.

(2) In the asymptotic conditions of sensibly infinite shearing stress, the width of the slippage zone does not increase if the relative cell volume of the blood is 0·5 or greater, but increases by a factor of about 2 if the relative cell volume is 0·4 or less.

(3) At zero shearing stress, the viscosity of the blood is some two to five times as great as the asymptotic minimum value if the relative cell volume is 0·4 or less ; and probably becomes infinite if the relative cell volume is 0·5 or greater.

It is inferred that the " viscosity " of blood depends on the shearing stress applied, but that there is no discontinuity in the relation between shearing stress and rate of shear. In the absence of any shearing stress, the red cells will cohere to one another and will form clumps, of varying sizes, which may join up so as to form a rigid structure. If a shearing stress is applied and increased progressively, the structure will break up into clumps, and the clumps eventually into individual cells, as Maude and Whitmore (1958) have pointed out. The clumps will enclose and " immobilize " appreciable volumes of serum, so that the effective relative cell volume will be increased ; as they break up the viscosity will fall correspondingly. In addition, when the blood is sheared, there may be an axial movement of the clumps and individual cells, and an orientation of the cells, both of which will have the effect of further reducing the viscosity of the layers of blood which are sheared. This effect may be responsible for the inferred increase in the width of the slippage zone when the rate of flow becomes greater.

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A Theoretical Treatment of the Differential Flow Velocities of Plasma and Corpuscles in Living Bodies

By R. L. Whitmore (Department of Mining and Fuels, University of Nottingham)

It is well known that when blood flows through the vessels of a living body a layer of plasma, devoid of red and white corpuscles, is seen to form at the vessel wall.[1] Experiments show that the width of the layer is a function of the velocity of flow[2], and the red cells travel faster than the plasma through the body.[3] The general conclusion is that the flow velocities are low enough for streamline conditions to prevail in most blood vessels and the force producing the axial accumulation of the cells (and hence their different flow velocity from the plasma) is hydrodynamic in origin.[1] The transit times are measured by labelling corpuscles and plasma with dyes or radioactive tracers and injecting them at one point in the circulation. Blood samples are collected at frequent intervals from another point, the quantity of labelled material which each contains is measured, and time/concentration curves for cells and plasma are obtained. If radioactive tracers are employed, the necessity of removing samples for analysis can be avoided by connecting a loop cannula in series with the blood vessel to be sampled and continually recording the concentration of labelled material in the cannula with a radiation-sensitive detector. A theoretical examination of the experimental technique shows that the simple concept of streamline flow and an axial concentration of corpuscles should produce time/concentration curves for cells and plasma which are initially practically superimposed and only

differ noticeably after the flow has continued for an appreciable time. In practice, however, the curves are significantly different in their initial stages or are bodily shifted relative to one another.[2] Acceleration forces caused by the pumping action of the heart are much too small to produce the observed effects but it may be shown that if the plasma in the core can freely exchange with that in the inner portion of the plasmatic layer, while the cells are restrained inside the axial core, a satisfactory explanation is possible. Such free exchange of plasma should give to the cells in the core a random motion and this phenomenon has, in fact, been reported.[4,5] The presence of a static outer layer of plasma, as required by the theory, has also been observed.[2] The non-streamline behaviour of the blood which the theory requires may be caused by the compliancy of the blood vessels and the corresponding rhythmic alteration in their diameter. During each cycle it is unlikely that the ratio of the volume of the plasmatic layer to the volume of the central core remains absolutely constant and, because the corpuscles are restrained within the core, the volume alterations must be made up by an exchange of plasma between the core and the sheared portion of the plasmatic layer. A corollary of the theory is that the constricting force exerted on the corpuscles cannot be hydrodynamic in origin and, because it can be shown[6,7] that published experimental data on the viscosity and concentration of whole blood and the differential velocity of cells and plasma flowing in glass tubes can be explained without assuming the presence of a plasmatic layer, it appears that the constricting force may only be present *in vivo*. It is obviously hazardous to guess what type of force could in fact be present and it is clear that more experimental and theoretical investigation is required.

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Velocity Profiles and Pulsatile Blood Flow

By D. A. McDonald (Department of Physiology, The Medical College of St. Bartholomew's Hospital, London)

The work to be discussed is that of a group in this Department (notably the late J. R. Womersley and Dr. M. G. Taylor) who have been investigating the hydrodynamics of pulsatile flow in the circulation. The emphasis, therefore, is mainly on the assessment of the approximations we have introduced in order to make this a tractable physical problem, rather than on the rheological properties of blood in elastic tubes *per se*. Two assumptions have been made which are of especial interest in the present symposium ; (a) that blood behaves approximately as a Newtonian liquid in arteries, i.e. anomalous viscous behaviour may be neglected; (b) that the flow is laminar.

(a) As will be seen below, in oscillatory flow there are great variations in the rate of shear in the vessel during the cardiac cycle and there are regions which have very low rates of shear at all times and the apparent viscosity of blood varies, as is well known, with the rate of shear. Nevertheless, TAYLOR (*Phys. Med. Biol.*, 1959, **3**, 273) has shown, theoretically, that the error introduced by using the asymptotic value for the viscosity of blood will be very small if it is used in the equations relating pressure and flow in arteries.

(b) The assumption of laminar flow is difficult to justify in large arteries. Values of the Reynolds number calculated from peak flow velocities can be very high—in the human aorta up to 30–40,000. Such conditions, however, are very transitory and at other moments in the cycle the value will be zero. The aortic valves, and the origins of branches, also undoubtedly cause instability due to the formation of large vortices. When, however, the equations of motion of the liquid are considered we find that in situations such as the larger mammalian arteries the inertia of the liquid determines the pressure–flow relationship to a much greater extent than its viscosity. The explanation of this is best illustrated by a study of the velocity profiles in oscillatory flow of sinusoidal form (HALE *et al.*, *J. Physiol.*, 1955, **128**, 625; review—MCDONALD and TAYLOR, *Progr. Biophys.*, 1959, **9**, 105). The dynamic similarities of oscillatory flow are determined by a non-dimensional parameter $\alpha = R(W/\nu)^{\frac{1}{2}}$ (R, radius of tube; W, the "circular" frequency; and ν, the kinematic viscosity). When α is small, e.g. <3, the velocity profile at peak flow is not very dissimilar to the parabolic profile seen in steady laminar flow. With larger values of α, e.g. >6, we find that the profile has become very flattened, so that there is a very small velocity-gradient in the central regions of the stream and appreciable shear is mainly confined to the laminae relatively close to the wall. At the root of the aorta in the dog the value of α for the pulse-frequency is 8–10, for the human ca.15. For the other harmonic components it is correspondingly higher. Under these conditions even established laminar flow behaves as if it were a "solid" mass oscillating within a thin viscous liquid sleeve. Experimentally, we find that the oscillatory flow curve computed from the pressure-gradient using the full equations is very little different from the curve calculated by assuming blood to be a non-viscous liquid. Interesting problems are raised by considering the "inlet" length for oscillatory flow—this also needs to be considered in the aorta.

Apparent Viscosity and Wall Adherence of Blood Systems

By A. L. COPLEY* (Medical Research Laboratories, Charing Cross Hospital, London)

In a number of recent publications [1–3], we reported on findings of apparent viscosity and wall adherence of blood, plasma and serum in contact with glass and fibrin surfaces. The latter surface which is blood-born was selected because it has been postulated that the inner or endo-endothelial lining of all blood vessels is covered by a film of fibrin which is constantly being formed and maintained, and also controlled by fibrinolytic processes in the more or less immobile layers of the plasmatic zone

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next the vessel wall. The apparent viscosities always showed a decrease when the blood systems were in contact with fibrin as compared with glass or other surfaces, suggesting that it seems doubtful whether results of all previous studies on viscosity of shed blood or plasma in glass tubes are directly applicable to blood and plasma circulating in living blood vessels. Measurements of wall adherence showed this to be lower when in contact with fibrin surface as compared with glass or other surfaces. Both the fall in apparent viscosity and wall adherence suggested that, physiologically, the proposed endo-endothelial fibrin film might constitute a major factor in aiding circulation by increasing the velocity of blood flow and regulating the width of the more or less immobile layers.

With regard to wall adherence, this is more marked in etched glass than on smooth glass ; but with fibrin surfaces, whether laid on roughened or smooth glass, the wall adherence is markedly less. In the living blood vessel the endo-endothelial lining is presumably not as smooth as polished glass. Although wall adherence, as measured from a moving index, gives no direct information about conditions in a full capillary, the phenomenon is certainly suggestive. In his contribution to the present Conference, Dr. Whitmore observes that there may be a constricting force *in vivo*, but rightly stresses that it would be hazardous to guess what type of force this could be.

When an index of 30 per cent red cell volume suspended in plasma, serum or saline passes along an artificial capillary, an increase of concentration of red cells is found in the shortened index at the end of its journey, although a minority of red cells remains in the wall adherent layer. This suggests the centralizing tendency of the cells within the capillary. The trapped minority of cells to be found in the wall layer is doubtless held by electro-chemical forces of various kinds. Nevertheless, within the living vessel, where there are no air surfaces, plasmatic zones can readily be seen.

The shape of the flow curve (shear rate vs. stress) when blood flows through a full glass capillary has long puzzled rheologists. Very approximately, blood behaves as a Bingham system, the flow curves extrapolating to an intercept on the stress axis. But the curve is not really linear. As long ago as 1942, COPLEY *et al.*[4] suggested the application of an equation proposed by HERSCHEL and BULKLEY[3] in which the shear rate is raised to a power differing slightly from unity. Even this was not fully satisfactory and, quite recently, SCOTT BLAIR [6] has shown that an equation proposed by CASSON[7] for varnishes and later applied by STEINER[8] to molten chocolate, gives excellent straight lines for blood, bovine and human, on both glass and fibrin surfaces. Following this equation, straight lines are obtained when the square root of the stress is plotted against the square root of the shear rate and the equation reduces to Poisseuille's law when the extrapolated intercept on the stress axis becomes zero. There is no invariance to changes in direction of flow, since negative stresses involve imaginary quantities, but the equation shows promise of useful practical application.

In the earlier experiments, the anticoagulant used was always heparin. Preliminary results are also reported using other anticoagulants.

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Turbulence of Blood Flow in the Vascular System of Man

By W. E. STEHBENS

(Sir William Dunn School of Pathology, Oxford University)

The localization of the intimal thickenings about the forks of the cerebral arteries of human foetuses and infants suggested that their aetiology might be dependent on haemodynamic factors. Therefore the possibility of turbulence occurring at bifurcations was investigated.

Experiments were performed using five glass models as analogues of the cerebral arteries. The first model consisted of a glass tube with an internal diameter of 1 cm, bent into an S-shape to resemble the carotid siphon of the internal carotid artery. The four other models were branched tubes, of which the main stem had an internal diameter of 1 cm, and each branch, a diameter of 0·7 cm. Model 2 was a T-piece. Models 3, 4 and 5 were Y-pieces with angles of bifurcation of 165°, 90° and 30° respectively. A steady flow of water under a constant pressure, was delivered to the model and turbulence of flow was examined by the dye injection technique at different velocities. In this way the approximate critical Reynolds number for each model under the conditions of the experiment was determined, during both forward and reverse flow.

In the straight tubing of 1 cm diameter, the critical Reynolds number was approximately 2000. At lower velocities, turbulence was induced in the S-shaped curve, wide angled bifurcations and at the unions of the streams, when the Reynolds number was less than 2000. This value is critical for flow in straight tubes but not for such disturbances of flow as were present in these models.

The critical Reynolds numbers for both blood and water are probably the same for similar conditions of flow. Application of the experimental findings to the human circulatory system suggests that 2000 is not the critical Reynolds number throughout the vascular tree. In the complicated vascular tree, in which branchings and anastomoses are frequent and enviromental conditions far from ideal, the critical Reynolds number would have to be estimated individually for any particular site and probably would be often less than 2000.

Reynolds numbers calculated for the mean velocity of arterial flow, overlook the fact that the flow is pulsatile. The peak velocity is much

higher than the mean velocity. The Reynolds number calculated for the peak velocity would then be considerably greater than values for the mean velocity. As turbulence may be induced intermittently, the Reynolds number at the peak velocity is important as shown by the observations of McDonald on flow in the rabbit aorta.

Reynolds numbers calculated for the human aorta will be over 11,000 for the peak velocity, and considerably higher during strenuous exertion. Theoretically, turbulence will also occur in much smaller arteries and in veins.

An abrupt increase in the diameter of a tube will induce turbulence. It is probable therefore that the pathological irregularities in the human vessels which occur in aneurysms, aortic stenosis and atherosclerotic narrowing of arteries, may favour turbulence of flow. The relationship of turbulence to the changes in the vessel wall is an aspect of the subject which requires further investigation.

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Some Measurements of Rheo-dichroism of Guinea-pig Blood Plasma

By H. H. Pfeiffer (Laboratorium für Polarisations-Mikroskopie, Bremen 1, Germany)

Former rheological experiments with guinea-pig blood plasma were made because, under some pathological conditions and also in pregnancy, a certain degree of anaemia is often associated with changes in viscosity of blood plasma. Inhibition of the clotting reaction of the plasma is effected by the use of such naturally occurring substances as heparin. All measurements of flow properties were made with capillary tube viscometers, principally of the Hess and Tsuda types. Flow- or rheo-dichroism, a well-established phenomenon found in many solutions and colloidal suspensions containing rod-shaped particles, is analogous to the flow-birefringence of liquids. The particles responsible for rheo-dichroism, flow-birefringence and double-refraction generally, in living systems, I have called " leptones " (see H. H. Pfeiffer, A. Frey-Wyssling, W. Seifriz, L. H. Bretschneider *et al.*). The term is convenient, since it refers to a variety of particles : molecules, micelles, plastids, chondriosomes, microsomes, cytonemata, etc. The phenomenon of rheo-dichroism owes its origin to the different light absorbing capacities of orientated leptones when viewed in a plane normal to their axis of alignment. Dichroism can often be revealed in materials by appropriate staining. In certain cases, organic dyes such as Congo red, toluidene blue or thionine may be attached to leptones in a flowing liquid, so that the molecules of the dye are so orientated as to endow the system with dichroic properties. Dichroism is thus often a very sensitive indication of orientation. A liquid is said to show positive dichroism with respect to some axis when it shows maximum absorption of polarized light in a plane parallel to this axis and negative dichroism when the plane is perpendicular to it.

Quantitative treatments of dichroism depend on measurements of absorption by spectro-photometric methods. The coefficients of absorption for the ordinary and extraordinary rays, determined by light trans-

mission through the preparation, are rather small. If l is the sample thickness and R its reflection coefficient, then we have, for the absorption coefficient k :

$$k = \frac{2 \log (1-R) - \log T}{4 \pi l \log_{10} e} \lambda_0$$

when T is the light transmission, i.e. I/I_0 when I_0 and I are the light intensities before and after passing through the preparation respectively.

In this equation, the wavelength of the light, λ_0, must be expressed in the same units as l. If the refractive index (n) of the liquid is known, there is no need to determine R, e.g. by using the double photo-cell method. R may be calculated from the equation $1-R=4n/(n+1)^2$. The amount of dichroism is given by the difference between the absorption coefficients k_1-k_2 which are determined for two planes of polarization. In this way it can be shown that, at constant viscosity, swelling rate, temperature and flow rate, rheo-dichroism in blood plasma gives curves of the same general form as does birefringence ; i.e. at first linear, then flattening out as flow-rate changes, finally reaching a limiting value which depends on viscosity, swelling rate and temperature. These regularities are due to an orientation of the leptones when the plasma is sheared.

Some experimental evidence of this orientation can be obtained by the direct observation of plasma flowing in a capillary tube. This appears brighter, reflects more and absorbs less of the incident light when in motion than when at rest. But is is not known whether this orientation agrees quantitatively with a theoretical statistical distribution. As a first approach, however, the difference between the extinctions of the two beams of polarized light, parallel and perpendicular to the electric vector, gives the desired information about the degreeof leptone orientation.

In conclusion, I would repeat a suggestion which I have made on several occasions and in several papers on rheo-dichroism. I think that, at a critical flow-rate, the leptones of blood-plasma are arranged temporarily in " cybotactic groups ". This results in an anisotropic structure which is manifested by rheo-dichroic behaviour. In former years, I believed that the destruction and re-forming of these incoherent aggregates of leptones must lead to non-Newtonian flow, but I now know that rheo-dichroism is not limited to non-Newtonian systems, but is a distinctive characteristic of all flow-birefringent systems.

Rheology of Blood Coagula

By G. W. Scott Blair (National Institute for Research in Dairying, University of Reading)

The method used for studying blood coagula is exactly the same as that described for milk gels, except that a narrower recorder capillary may be used, since some lag due to the viscosity of the air is not of importance in studying a system showing no appreciable delayed elasticity. This allows a greater magnification of the displacements.

Whereas milk is coagulated by the action of predominantly a single enzyme (rennin), the process of blood coagulation is far more complex.

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It is, therefore, all the more remarkable that the rheological behaviour of blood coagulum (bovine and human) during all but the earliest stages of coagulation, is much simpler than that of milk gel, at least under the conditions of our experiments.

Blood is drawn, taking the usual precautions, from the jugular vein of a cow or, by a medical man, from the antecubital vein of a human subject. (A micro-apparatus requiring only 1 ml of blood has been described[1] but more accurate data are obtained using 50 ml, as with milk.) After rejecting the first few millimeters, the sample is collected in a silicone-coated vessel and a suitable coagulant is added. The use of glass beads has not proved sufficiently reproducible and either aqueous bovine brain-extract or COPLEY's plasma geloplastin[2], which can be prepared by the action of Lloyd's reagent on plasma from the same animal, has normally been used. The blood is immediately transferred to the U-tube, which is coated with silicone, and the surfaces are covered with a layer of kerosene to prevent any contact with air.

The process of coagulation may be followed, exactly as with milk, except that 15 sec loading and 15 sec recovery give ample time for equilibrium conditions to be reached.[3]

The sigmoid character of the rigidity modulus–time curve is much more marked with blood than with milk ; but, if the rigidity modulus is plotted against log $(t-t_0)$, where t is the time since the addition of the coagulant and t_0 that at which clotting is first observed for an independent sample in a silicone-treated test tube, good straight central portions of the curve can often be obtained. The slopes of these give a useful measure of the rate of coagulation during all but the earliest and latest stages of this process. A constant temperature of 32°C has generally been used in these experiments.

As with milk, it is found that factors which affect coagulation may influence t_0 and the setting rate in entirely independent ways, suggesting that both starting time and rate of coagulation should be measured if the coagulating properties of blood samples are to be compared.

When a well-set coagulum is subjected to a " creep " experiment, the curves obtained are extremely simple. When a constant pressure is applied, if a wide recorder capillary is used, the displacement almost immediately jumps to a finite value, corresponding to a single rigidity modulus. While stress is maintained, an almost linear curve indicates viscous flow. When stress is subsequently removed, there is an immediate elastic recovery, showing (unlike milk gel) little or no static fatigue and no appreciable elastic after-effect. The coagulum may therefore be described as a Maxwell body having only one viscous constant. This behaviour also holds at least approximately when loads are progressively increased and diminished, there being no signs of hysteresis loops. Constant strain relaxation experiments show a single Maxwellian relaxation time in all but the latest stages of the process, though towards the end, the relaxation time often seems to decrease for reasons still unknown.

If blood is tested very frequently during setting, the coagulation process sometimes seems to be slightly slowed down, but speeds up again if the

sample is rested. This probably reflects a very slight thixotropy and suggests the advisability of a fairly even spacing, on a logarithmic time scale, of readings during coagulation.

The use of other coagulants or of blood from other species, or under pathological conditions, may not produce such rheologically simple coagula ; but those coagula so far studied all appear to approximate closely to Maxwellian behaviour.

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Thrombelastography: Physical and Physiological Aspects

By Hellmut Hartert (Medizinische Universitats-Klinik, Heidelberg, Germany)

Thrombelastography is a method for the examination of blood clotting. It measures continuously—i.e. every 4–5 sec—the shear elasticity of the blood clot from the moment when the first fibrin strands have been formed to the moment when the whole clot has been built up ; or to the moment when the clot has totally disintegrated by fibrinolysis. At every instant, the amplitude of the photokymographically recorded double-curve gives the instantaneous shear elasticity. From the curve, the clotting time can be read as well as the velocity of clot formation, after it has begun. Partial or complete fibrinolysis can also be seen in the same way. There has been controversy as to whether the thrombelastograph (TEGraph) measures shear elasticity in the fibrin clot or something else. Fibrinogen which has been clotted by relatively pure thrombin shows indeed no typical elasticity. Yet the clot which has formed in normal platelet-containing plasma shows pronounced elastic behaviour ; it gives nearly linear force–tension curves in the range of usually measured forces. This means that there is a great difference between natural clots and the fibrin clots produced by purified substances. It is therefore not permissible to draw wide conclusions from the physical qualities of such fibrin products, about the structure of a natural blood clot.

To form a clot at a normal speed and having normal elasticity three substances seem to be necessary as well as fibrinogen and thrombin ; platelets, calcium and normal serum. The lack of only one of these ingredients produces a rather narrowed amplitude in the thrombelastogram (TEG) ; which means a low shear elasticity. In serum the normal ionic milieu and a protein-like substance, which is different from the known clotting factors, are important. In our laboratory some biochemical data were found concerning this substance, which we previously called the retraction cofactor. The factor is not active in plasma ; it is activated parallel with prothrombin consumption and is relatively stable against storage and heat being unstable against freezing. It is not adsorbable in barium sulphate, barium carbonate and aluminium hydroxide. It can be precipitated at a pH of 5·1–5·3 and is reactivated if redissolved in a serum which is freed from protein by heating.

The shear elasticity of the clot, as measured by the TEGraph is strongly influenced by the fact that, simultaneously with the formation of the fibrin strands, retraction begins to act, provided that platelets are present. It was shown in 1949 in our laboratory, that retraction starts immediately with fibrin formation and that the seeming delay of the start of retractive tension, as shown with other methods, is only a methodological error.

With a newly developed method, " retractography ", it can be shown that retraction starts immediately at the clotting point and increases in the same fashion as does the TEG. Thus the production of fibrinogen strands seems to run quite parallel to its retractive tendency. The TEG therefore indicates elasticity and " tonus " of the clot integratively. With the TEG alone, it is not possible to separate the two phenomena, since a control specimen with platelet-free plasma not only lacks the retractive power but also the strong structure-producing effect of the platelets which link the network by increasing the " knots " between the fibrin strands.

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Rheological Considerations on the Haemolyzing Red Blood Cell

By A. KATCHALSKY (Weizmann Institute of Science, Rehovoth), H. KLIBANSKY and A. DE VRIES (Beilinson Hospital, Petah Tiqva, Israel)

The present study is concerned with the behaviour of the red cell subjected to the process of gradual haemolysis, that is the liberation of haemoglobin from the red cell suspended in an isotonic medium, the ionic strength of which is gradually decreased by dialysis against hypotonic solutions. By this procedure of gradual haemolysis, a high percentage of " ghosts " with electron-microscopically intact membrane is obtained.[1] This study is an extension of an investigation on the introduction of proteins into the red cell ghost under conditions of reversible opening of large pores in the cell membrane.[2]

The dependence of the percentage haemolysis on the equilibrium sodium chloride concentration reached at the end of the dialysis was determined. In certain blood samples the percentage haemolysis remained low until an equilibrium concentration of 0·06 N was reached. Further decrease in the equilibrium concentration by less than 0·02 N caused a sudden increase in percentage haemolysis up to about 80 per cent then a slow increase with further decrease in salt concentration. The critical concentration of 0·06 N corresponds to a red cell volume increased by 1·76-fold, i.e. to the maximal volume of an inflated red cell.[3]

The following explanation is proposed for this behaviour of the cell. As soon as the equilibrium concentration drops below 0·06 N, the stresses which develop in the membrane open up pores, sufficiently to allow penetration of salt ions into the cell, so as to establish a Donnan equilibrium. The osmotic forces thus developed cause a rapid influx of water leading to a sudden widening of the pores to dimensions allowing the passage of haemoglobin molecules. When the haemoglobin concentration in the red cell has decreased sufficiently, the influx of water ceases and the pores close. This behaviour of the red cell is considered to be representative of a red cell population with a sharp size distribution. With other blood samples a sudden increase in percentage of haemolysis

occurred also at about 0·06 N. However, the curves obtained were less steep, presumably indicating a wider distribution in cell size or haemoglobin content.

A comparison of the percentage of haemolysis obtained by a gradual haemolysis, with that obtained by the classical osmotic fragility test procedure, in which the red cells are thrown directly into hypotonic solutions, showed that similarly shaped curves were obtained with the latter procedure. However, the parallel curves were shifted to about 0·01 N higher salt concentrations. Thus, using this drastic procedure, haemolysis occurs when the red cell volume is markedly smaller than in the case of gradual haemolysis. It seems that this shift in the curve is due to the difference in the rate of penetration of water into the cell. In the case of drastic haemolysis the rate is higher and correspondingly larger stresses are developed in the membrane, thus permitting an opening of pores at higher salt concentrations.

Equilibrating red cells with hypotonic sodium chloride solutions of concentrations higher than 0·08 N (i.e. a concentration range at which no haemolysis occurs) and subsequently throwing the cells into salt solutions of haemolyzing concentrations, gave percentage haemolysis curves similar to those obtained when starting with cells in an isotonic medium. It seems as if the red cell, in salt solutions of concentration higher than 0·08 N, behaves as a still slightly inflated football bladder. Only with further inflation, corresponding to lower salt concentrations, stresses will develop in the membrane.[4] The rheological behaviour of the red cell membrane in the concentration range of 0·08–0·06 N resembles that of a Kelvin body.[5] Conforming to the characteristics of the Kelvin body, relief of stress is accompanied by reversal of the ghost to the original bidiscoid shape and osmotic properties. Furthermore, the strength of the membrane of the inflated cell is greater at higher rates of straining, i.e. at higher rates of water influx, as demonstrated by subjecting the red cell to different osmotic gradients.

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